LISA

SE&I Pre-Proposal Meeting

May 13, 2003

NASA

esa

Agenda

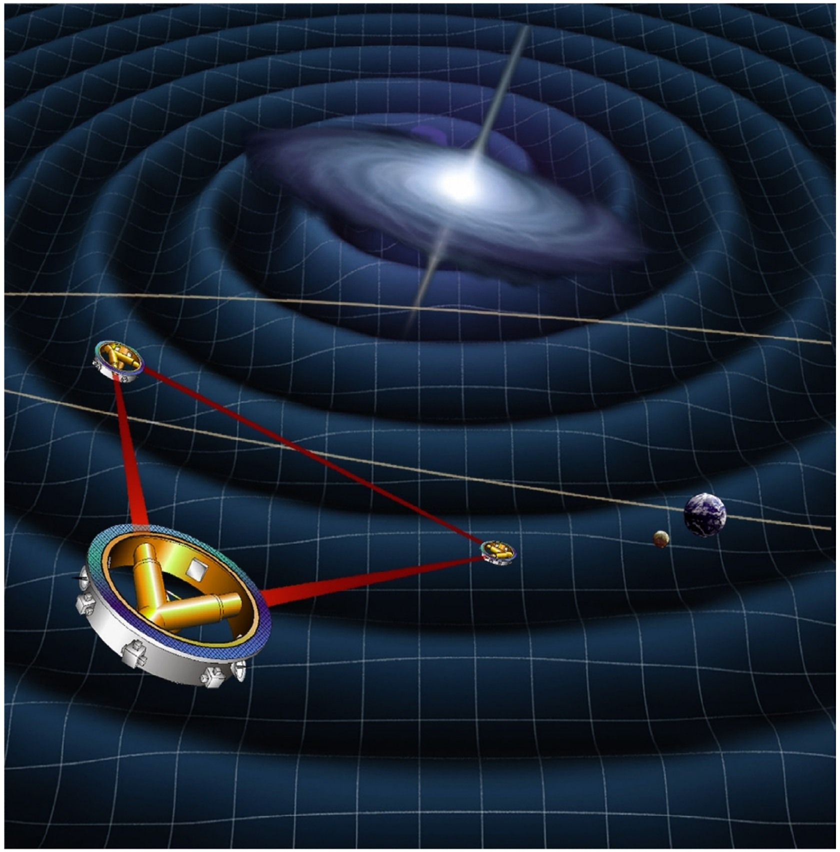
9:00 - 9:20	Welcome	Tuck Stebbins
9:20 – 9:30	Agenda	Colleen McGraw
9:30 – 10:30	System Engineering Management	Colleen McGraw
10:30 – 11:00	Break	
11:00 – 12:00	LISA Science & Experiment Design	Tuck Stebbins
12:00 – 1:00	Lunch	
1:00 – 1:30	LISA Architecture and I&T Overview	Mark Herring
1:30 – 1:45	Integrated Modeling	Stephen Merkowitz
1:45 – 2:00	Technical Challenges	Stephen Merkowitz
2:00 – 2:30	ITAR	Kevin Miller
2:30 – 3:00	Break	
3:00 – 3:20	Procurement Strategy & Schedule	Jerry Edmond
3:20 – 4:00	Task Assignments	Mark Herring, Jordan Camp
4:00 – 5:00	Q&A	All

Systems Engineering Management

Colleen McGraw

LISA Overview

Beyond Einstein: From the Big Bang to Black Holes



- The Laser Interferometer Space Antenna (LISA) is an exciting science mission designed to detect gravitational waves from space
  - Provides an ability to view the Universe in a way we never saw before!
- The mission consists of three drag-free spacecraft nominally forming an equilateral triangle with 5 million kilometer arms. The constellation is placed in a heliocentric orbit
- Spacetime strains induced by gravitational waves are detected by measuring changes in the separation between masses using laser interferometry
- LISA is a joint NASA-ESA mission which enters Formulation in the summer of 2003 and launches in 2011

Organizational Chart Drivers

- LISA's science is unique
  - Detecting gravitational waves from space
- LISA's partnering agreement is unique
  - The mission is an equal partnership between NASA and ESA
- LISA's system engineering is unique
  - The three spacecraft functioning as one system constitutes the measurement system. LISA is one integrated system
  - The systems perspective is essential throughout the entire lifecycle

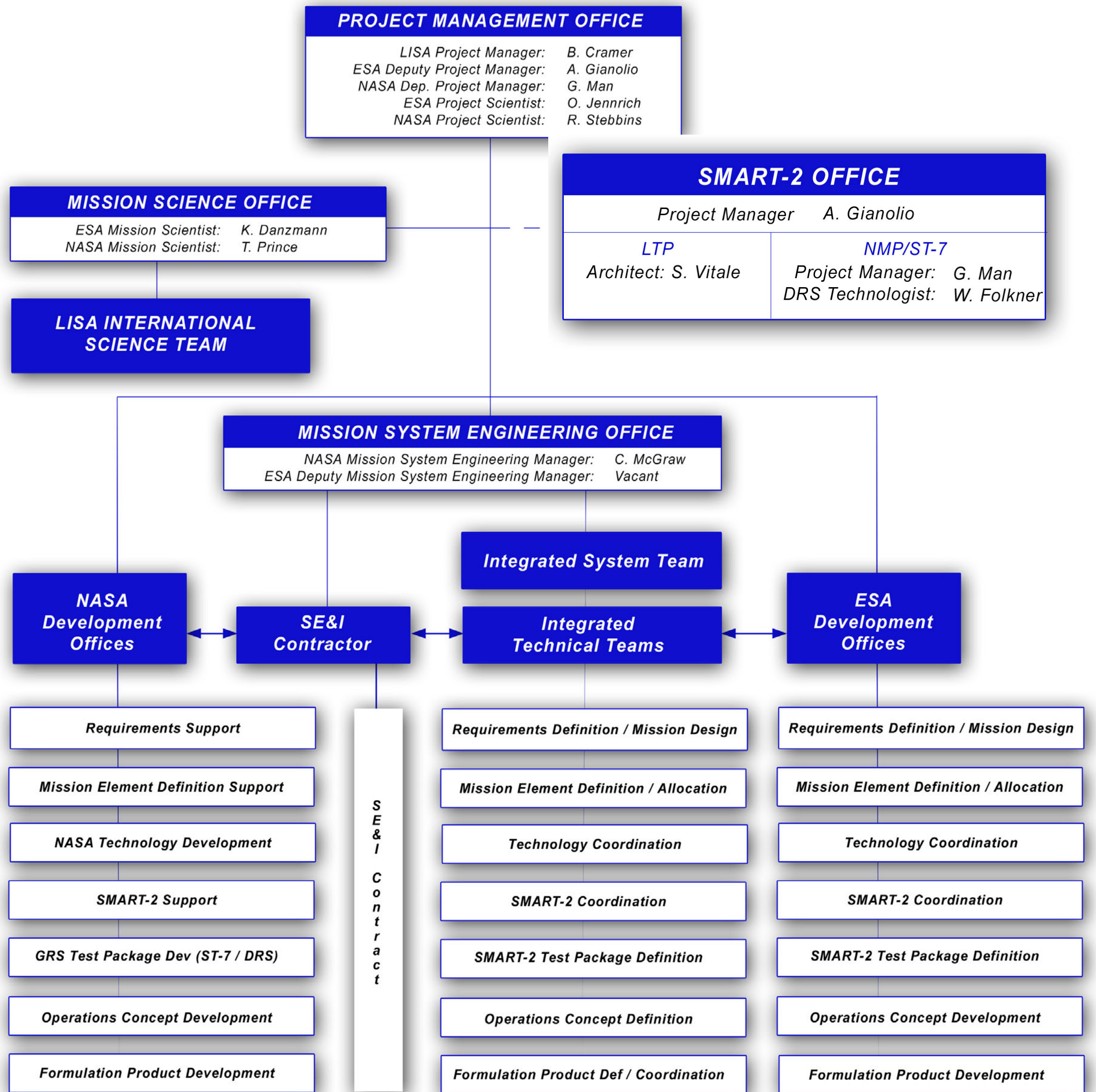
Project Roles & Responsibilities

Beyond Einstein: From the Big Bang to Black Holes

- Roles and responsibilities are assigned on the strengths of each partner
- NASA/ GSFC emphasis is on:
  - Project management
  - System engineering
  - Software management
  - Observatory and constellation I&T
  - Launch vehicle procurement & processing
- JPL emphasis is on:
  - Mission Science
  - Payload management
  - Payload components and payload integration
  - Operations
- ESA emphasis is on:
  - Three Spacecraft
  - Three Propulsion Modules
  - Key payload components
  - Intermediate payload integration

Organizational Chart

Beyond Einstein: From the Big Bang to Black Holes



Systems Engineering Office

- The System Engineering Office (SEO) is responsible for ensuring system level coherence of all design and developmental activities of all project elements and ensures technical coherence of the LISA mission
- System engineering capabilities are located within several Project elements, but their technical activities are coordinated through ONE System Engineering Team
- The SEO is responsible for the technical integrity of the mission including: systems, payload, spacecraft, ground system, and launch vehicle
- NASA and ESA share the management of the SEO however, NASA/GSFC has the lead for day-to-day activities
- SEO employs Integrated Technical Teams (ITT) and the Integrated Systems Team (IST) to facilitate collaboration between NASA and ESA

Integrated Systems Team

- The Integrated Systems Team accommodates the interests of both NASA and ESA
- Allows LISA to capitalize on the expertise in the US and Europe
- Is located within the SEO and co-chaired by the NASA/ESA System Engineering Managers
- Comprised of 6 scientists and 6 engineers from GSFC, JPL, ESA, and ESA member states
- The IST is a cohesive technical team that assists the SEO in orchestrating the evolution of the design throughout all phases of the mission
- IST supports the SEO with technical decisions

Integrated Technical Teams

- Integrated Technical Teams (ITT) accommodate each partner's interest
- Allows LISA to capitalize on the expertise in the US and Europe
- Integrated teams comprised of relevant members from NASA, ESA, and both SE&I contractors
- During formulation, ITT's emphasis is on design and definition
- During implementation, emphasis shifts to monitoring progress of the development, evaluating potential changes, and maintaining previously established ICD's
- Examples may include Operations, Mission Design, DRS, etc.

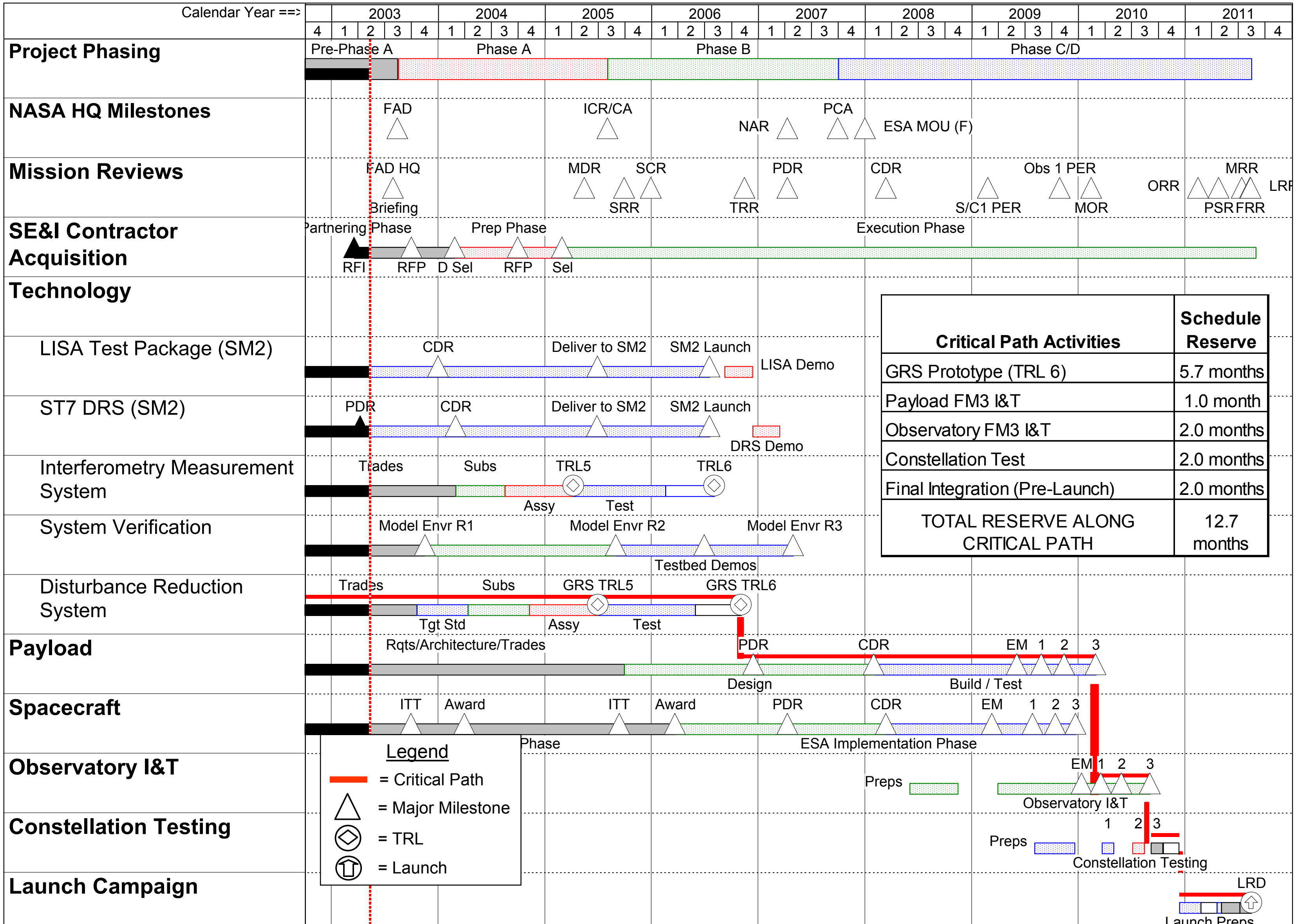
SE&I Contractor

- NASA SE&I contractor provides support to the GSFC SEO and the JPL Payload Office throughout the project lifecycle
  - Tasks may include requirements flow down, system verification and validation, interface definition and management, operations concept definition, design definition, software system engineering and risk management
  - In addition, the SE&I contractor may be responsible for payload and observatory integration and test, knowledge management systems, ground support fixtures and simulators, and development of mission software
- Major role of SE&I contractor is the staffing and coordination of the ITTs

LISA Project Master Schedule

SE&I Pre-Proposal Meeting

Beyond Einstein: From the Big Bang to Black Holes



Critical Path Activities	Schedule Reserve
GRS Prototype (TRL 6)	5.7 months
Payload FM3 I&T	1.0 month
Observatory FM3 I&T	2.0 months
Constellation Test	2.0 months
Final Integration (Pre-Launch)	2.0 months
TOTAL RESERVE ALONG CRITICAL PATH	12.7 months

System Engineering Challenges

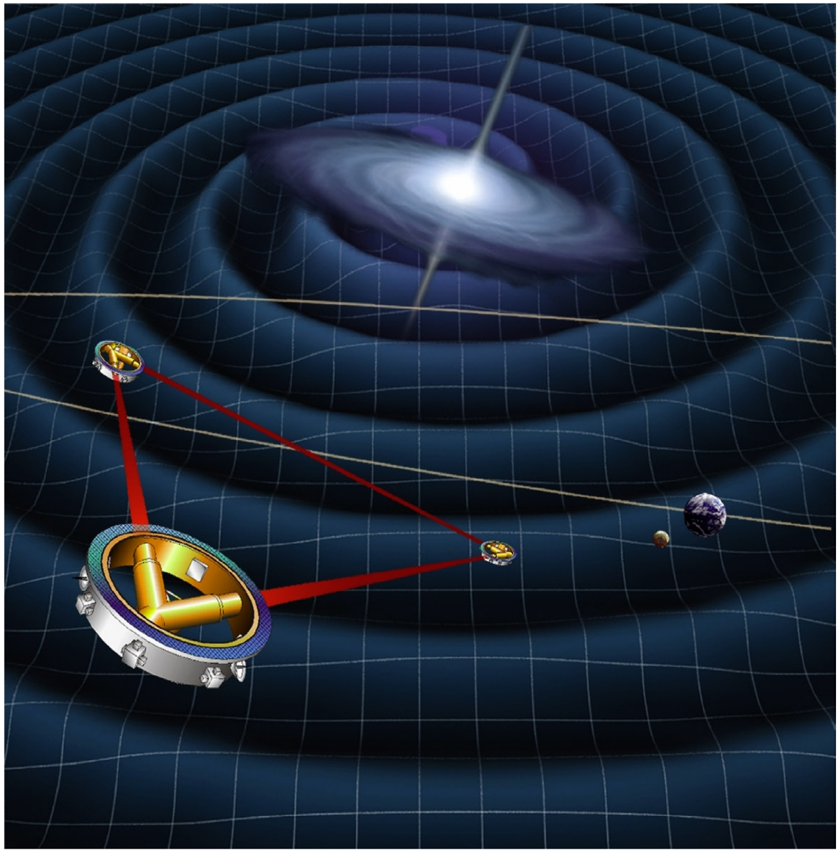
- Coordination of engineering efforts given the multiple teams located in multiple countries
- Hardware components from multiple facilities including NASA, Universities, Industry, ESA, and European Member States
- The Systems Engineering Office must have insight and track technical progress at a much lower level than previously done on NASA missions
- The three spacecraft must act as ONE system
- The technical and organizational integrated nature of LISA calls for a unique System Engineering organization

LISA Science and Concept

Robin T. Stebbins

LISA Overview

Beyond Einstein: From the Big Bang to Black Holes



- The Laser Interferometer Space Antenna (LISA) is a joint ESA-NASA mission to design, build and operate a space-based gravitational wave detector
- The 5 million kilometer long detector will consist of three spacecraft orbiting the Sun in formation
- Space-time strains induced by gravitational waves are detected by measuring the separation of fiducial masses with laser interferometry
- LISA is expected to detect signals from merging supermassive black holes, compact stellar objects spiraling into supermassive black holes in galactic nuclei, thousands of close binaries of compact objects in the Milky Way and possibly backgrounds of cosmological origin

A New Approach to Astrophysics

- Gravity is the dominant force in the Universe
  - Creates planets, stars, clusters of stars, galaxies, clusters of galaxies and compact objects
- Compact objects
  - Mass aggregations more dense than normal stars
  - Compact objects come in a wide range of sizes
  - Changing mass distributions make gravitational waves
- (Mostly) Binary systems (Big bad billiard balls of the Universe)
  - Supermassive black holes from galaxy mergers
  - Building up supermassive black holes from mergers of intermediate/seed mass black holes
  - Big black holes capturing small compact objects
  - Stellar-sized binaries
  - “Other”

What Are Gravitational Waves?

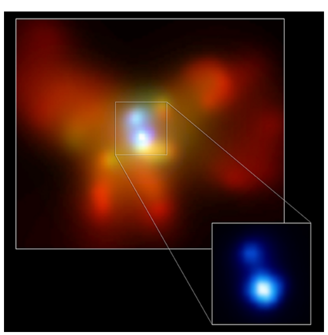
- Electromagnetic analogy
  - The radiative form of gravity, analogous to radio or light waves
  - Mass is the "charge" (no negative charge)
- What are they?
  - A strain in space-time. Propagating ripples in space-time.
  - Fractional length change, $\Delta L/L$
  - Typical strains are very small, even with large masses. (Space-time is stiff. Coupling between matter and waves is very weak. Very little interaction with intervening matter.)
  - Measure ΔL, so prefer big L
  - Propagate at the speed of light
  - Quadrupolar with two polarizations, no dipolar.
- How are they made
  - Changing mass quadrupole
  - Time varying mass distributions
- How are they felt
  - Ring of masses
  - Corks on the pond

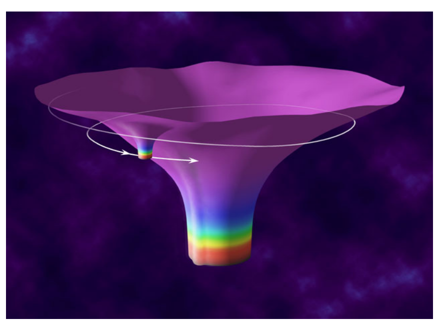
LISA Science Goals & Sources

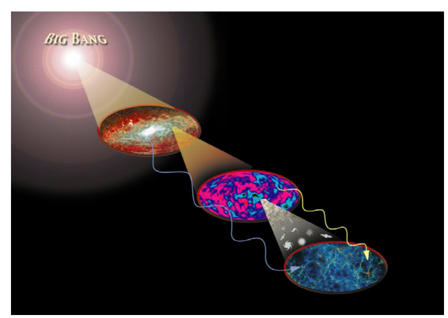
Beyond Einstein: From the Big Bang to Black Holes

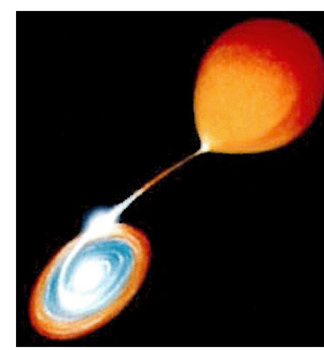
- Determine the role of massive black holes in galaxy evolution
- Make precision tests of Einstein’s Theory of Relativity
- Determine the population of ultra-compact binaries in the Galaxy
- Probe the physics of the early universe

- Merging supermassive black holes
- Merging intermediate-mass/seed black holes
- Gravitational captures
- Galactic and verification binaries
- Cosmological backgrounds and bursts

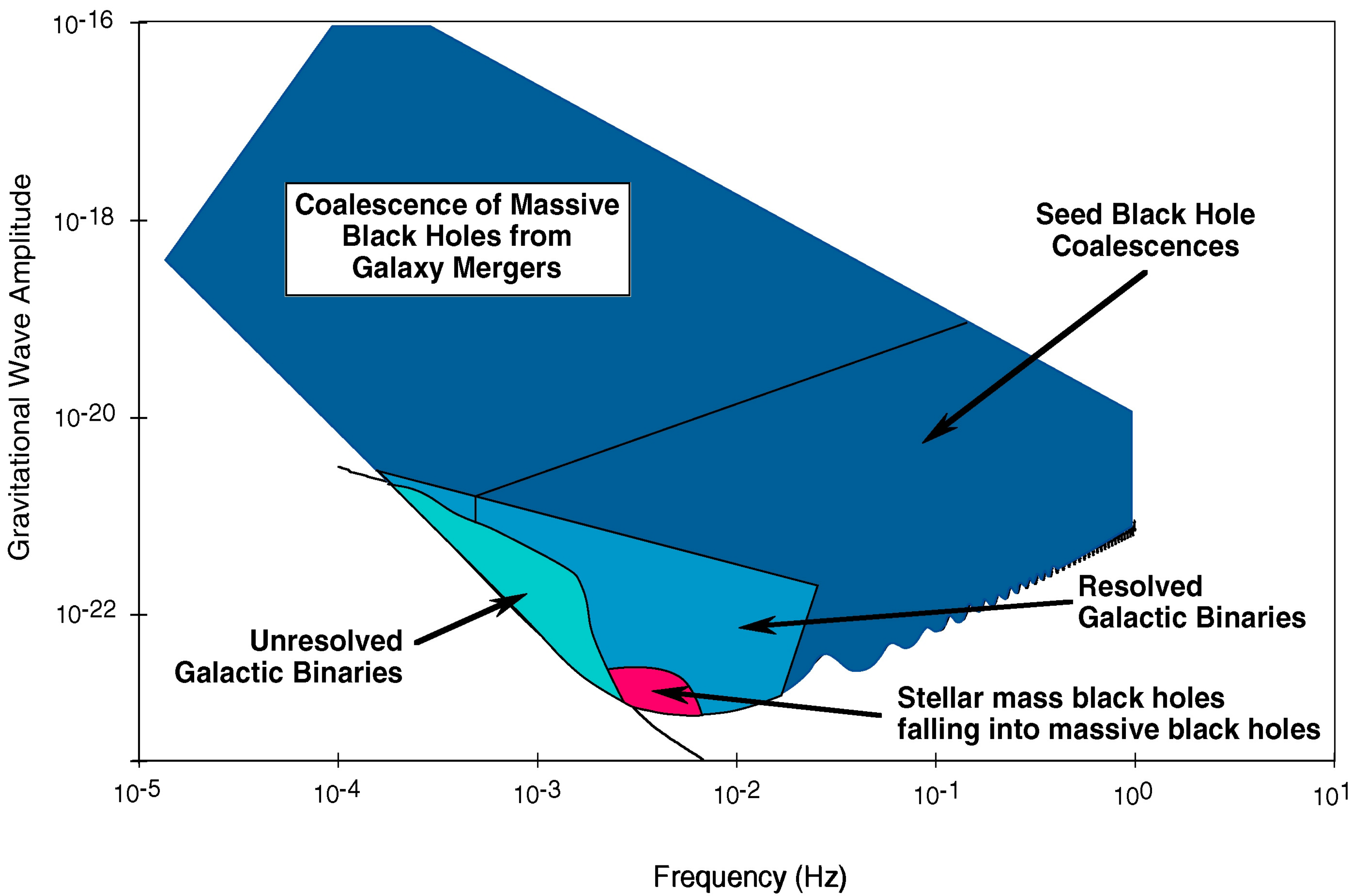








Sensitivity and Sources



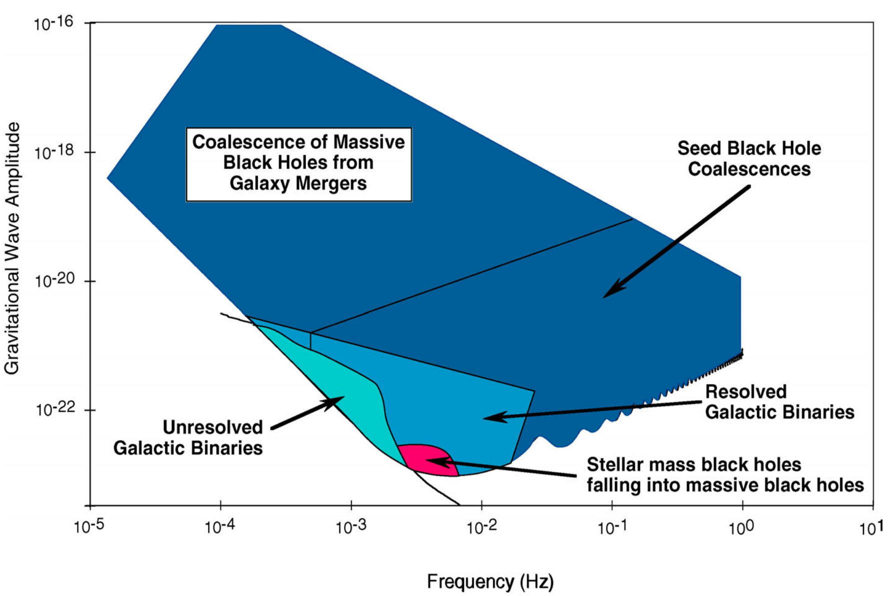
How Do You Detect GWs?

- A strain in space-time, propagating ripples
- Put out an array of reference masses to move with space-time.
- Monitor changes in separation between the array of masses, with requisite sensitivity
- Protect masses from disturbances that would mask the gravitational waves
- Other detection methods:
  - Resonant detectors
  - Ground-based interferometers: LIGO, GEO, Virgo, TAMA, ACIGA
  - Other space-based: spacecraft ranging

Measurement Parameters and Sensitivity

Beyond Einstein: From the Big Bang to Black Holes

- Measurement Parameters:
  - Acceleration requirement
  - Measurement sensitivity requirement
  - Arm length
  - Integration time
- How measurement parameters affects sensitivity
- Sensitivity curve

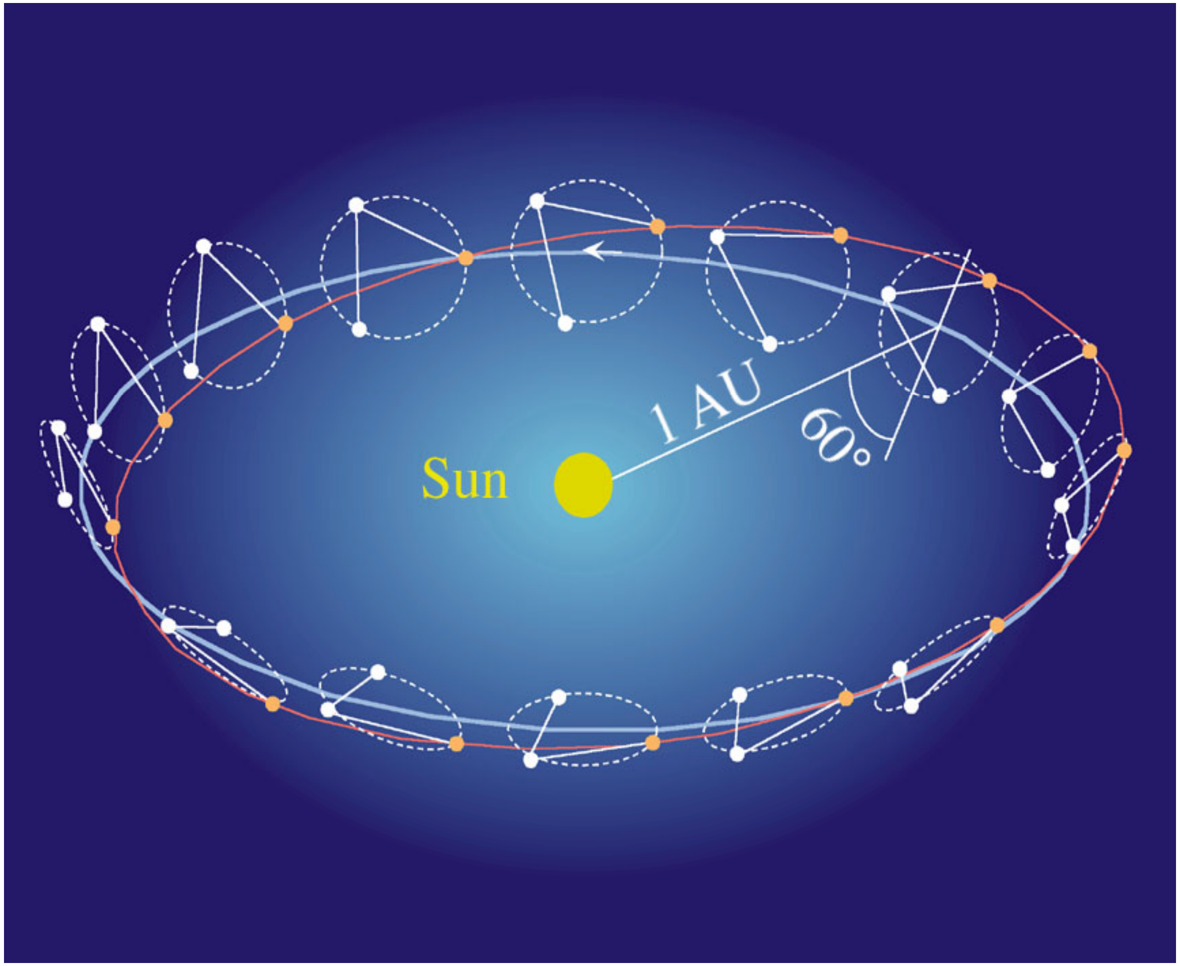


Measurement Concept

- Measure time-varying strain in space-time by interferometrically monitoring changes in three 5 million kilometer long arms
- The three arms:
  - Form an equilateral triangle
  - Are defined by six proof masses, located in pairs at the vertices of the triangle
  - Are monitored interferometrically to achieve a measurement bandwidth from 10^{-4} to 10^{-1} Hz
- A spacecraft at each vertex houses the two proof masses and the interferometry equipment. The formation orbits the Sun 20° behind the Earth.
- The proof masses are protected from disturbances by careful design and "drag-free" operation (i.e., the mass is free-falling, but enclosed and followed by the spacecraft)
- Lasers at each end of each arm operate in a "transponder" mode. Optical path difference changes, laser frequency noise, and clock noise are determined
- Three arms measure both polarizations of quadrupolar waves. Source direction is decoded from amplitude, frequency, and phase modulation caused by annual orbital motion.

Orbit

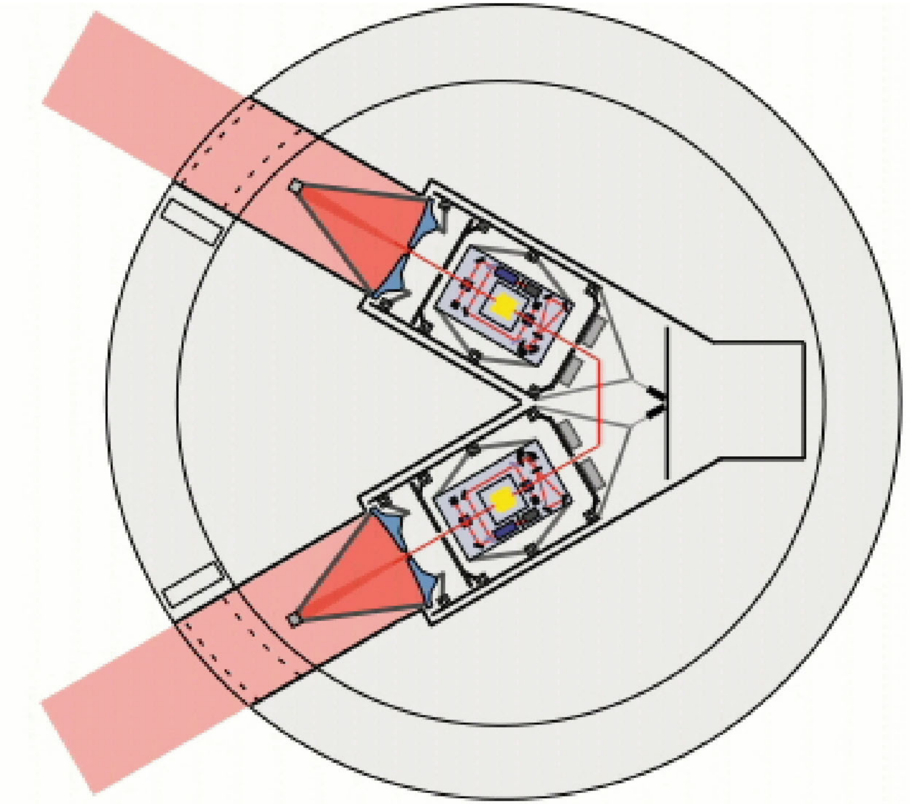
- Formation trails Earth by 20°; approximately constant arm-length
- Spacecraft have constant solar illumination and benign environment

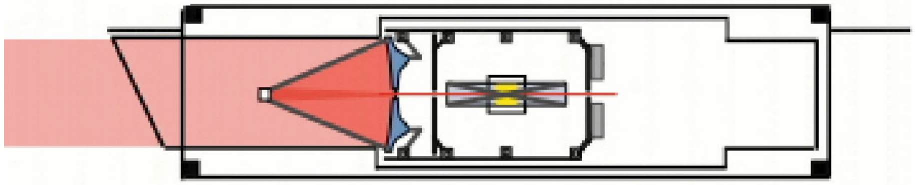


Disturbance Reduction System

Beyond Einstein: From the Big Bang to Black Holes

- GRS:
  - Proof mass
  - Electrostatic sensing
  - Electrostatic actuation
  - Charge control
- Microthrusters:
  - Liquid metal ion emitters
  - Neutralizers
- Control Laws
- Integrated spacecraft / payload design features





DRS Operation

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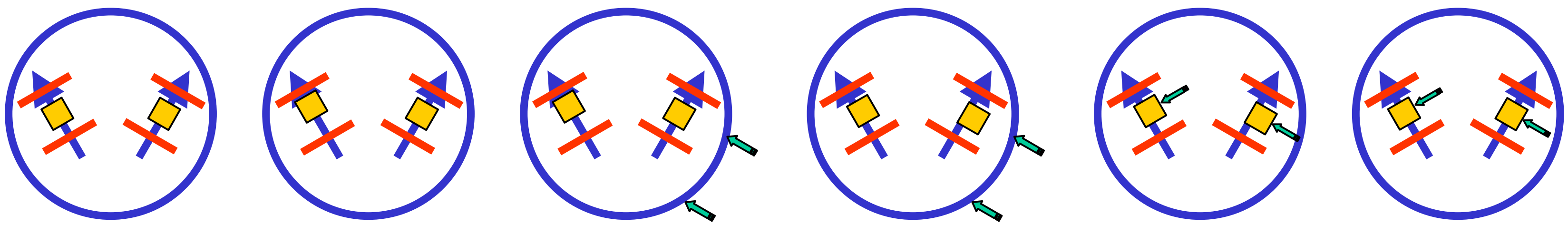
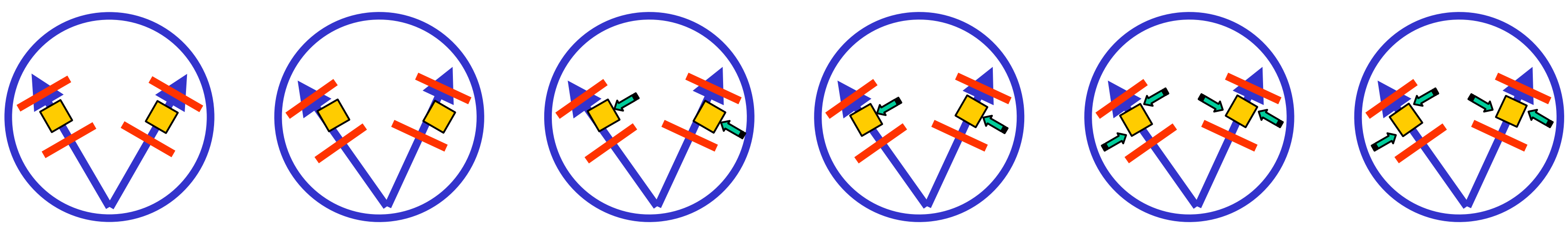
How the disturbance reduction system follows two proof masses with one spacecraft?

Left hand proof mass moves along measurement direction:



Spacecraft rotates with respect to the proof masses:



Interferometry Measurement System

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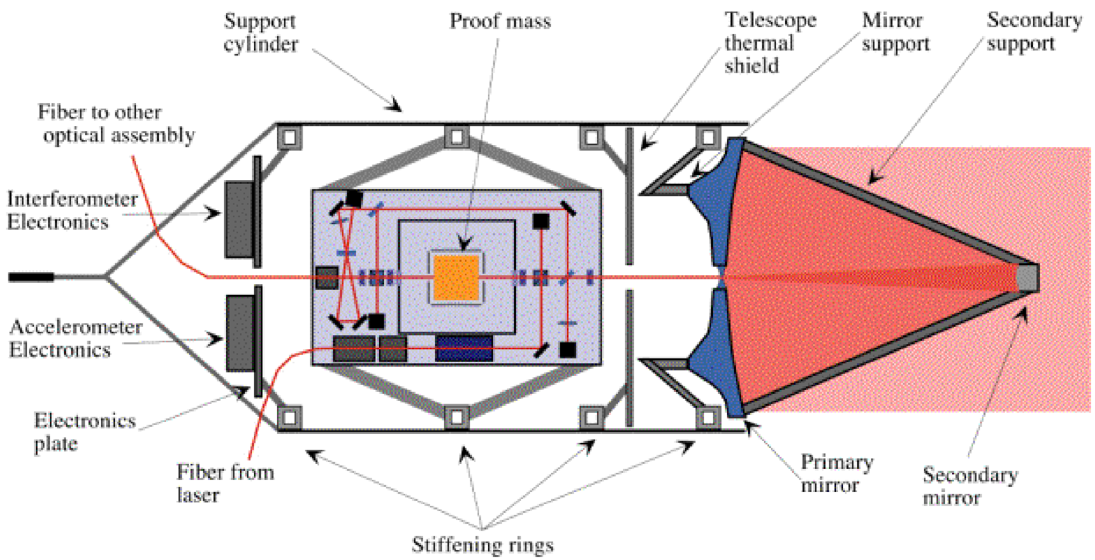


- 30 cm, *f*/1 transmit/receive telescope
- Optical bench with interferometry optics, laser stabilization
- Gravitational reference sensor
- 1 W diode-pumped, Yb:YAG laser, plus spare
- Fringe tracking and timing electronics, including ultra-stable oscillator
- System for comparing phase information from two arms

IMS Cartoon

- The distance monitoring system is a continuous ranging system using optical frequencies, like spacecraft tracking
- The ranging system senses:
  - Inter-spacecraft doppler motions
  - Temporal variations of laser frequency
  - Time variations of the optical pathlength between proof masses
- The phasemeter measures the accumulated phase as a function of time
- The science signal appears as a phase modulation in the beat signal

Requirements

Source	Spectral Amplitude (1×10^{-4}Hz)	Spectral Amplitude (1×10^{-3} Hz)	Spectral Amplitude (5×10^{-3} Hz)	Spectral Amplitude (1×10^{-2} Hz)	Observation Time (Yrs)
Merging supermassive black holes	4×10^{-17}	8×10^{-19}	1×10^{-19}	N/A	5 (3 arms required)
Intermediate-mass/seed black holes	N/A	3×10^{-19}	2×10^{-20}	2×10^{-20}	1
Gravitational capture from nuclear star clusters	N/A	3×10^{-19}	1×10^{-20}	1.5×10^{-20}	3
Galactic binaries and verification binaries	N/A	3×10^{-19}	3.5×10^{-20}	N/A	2
Cosmological backgrounds	N/A	N/A	N/A	N/A	1 (3 arms required)
Overall Requirement	**4×10^{-17}**	**3×10^{-19}**	**1×10^{-20}**	**1.5×10^{-20}**	**5** (3 arms required)

Table D-1 Derived Science Requirements

Parameter	Requirement	Error Estimate	Margin
Arm length	5×10^{6} km	N/A	N/A
Spurious acceleration (per proof mass)	3×10^{-15} m/s²/√Hz, 0.1 to 1 mHz	2.0×10^{-15} m/s²/√Hz, 0.1 to 1 mHz	119%
Measurement sensitivity (round trip)	4×10^{-11} m/√Hz, 1-100 mHz	2.8×10^{-11} m/√Hz, 1-100 mHz	53%
Integration time	1 year	N/A	N/A

Mission Performance Requirements, Error Estimates, Margins

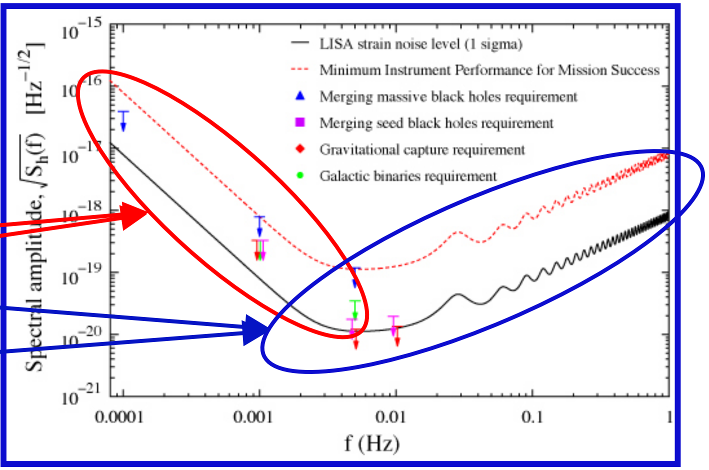


Fig. D-7 Instrument Performance and Science Requirements

Requirements

Beyond Einstein: From the Big Bang to Black Holes

- Acceleration Noise: $\times 10^{-16}\ \mathrm{m/s^2/\sqrt{Hz}}$

	Allocation	Error Estimate	Margin
Cross-talk	10.0	7.9	26%
Random charging	10.0	7.0	43%
Thermal distortion of S/C	10.0	5.0	100%
Residual gas	10.0	3.0	233%
Back action from position sensing	10.0	2.5	300%
Dielectric losses	10.0	2.4	317%
Fluctuating applied voltages	5.0	2.0	150%
Magnetic damping	5.0	2.0	150%
Magnetic remanence	5.0	2.0	150%
Fluctuating applied voltages	5.0	2.0	150%
Remainder of Noise force on S/C	5.0	1.6	218%
Remainder of Magnetics S/C	5.0	1.0	400%
Gravity noise from S/C motion	5.0	1.0	400%
Radiation pressure	3.0	1.0	200%
Other small effects	10.8	2.9	266%
Quadratic Sum	**30.00**	**13.71**	**119%**

Requirements

- Displacement Noise:

		x10^-12 m/¦Hz		
Effect	Number	Allocation	Error Estimate	Margin
Shot noise (photon statistics)	4	11.0	10.0	10%
Laser beam pointing noise	4	10.0	5.0	100%
Oscillator frequency noise	1	10.0	5.0	100%
Residual laser frequency noise	1	10.0	5.0	100%
Phase measurement and transponder lock	4	5.0	2.5	100%
Stray light effects	4	5.0	2.5	100%
Other substantial effects	32	3.0	1.5	100%
Combined Total (quadratic sum with Number multiplier)		**39.6**	**25.9**	53%

Summary

- LISA promises extraordinary science:
  - Guaranteed to see thousands of gravitational wave sources
  - Most violent events in the Universe since the Big Bang
  - Can see back the "Dark Ages" of the Universe
- The LISA mission concept applies known technologies in novel ways:
  - Drag-free technology
  - Spaceborne accelerometry
  - Interferometric ranging
  - The "instrument" is the constellation of spacecraft

System Architecture

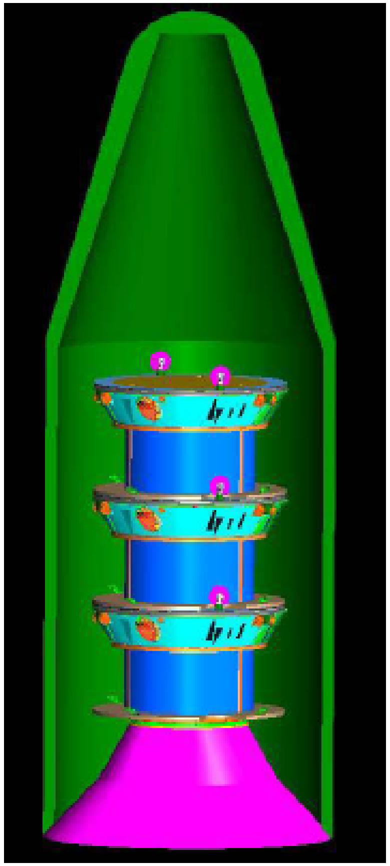
Mark Herring

(Stephen Merkowitz Presenting)

Launch and Cruise

Beyond Einstein: From the Big Bang to Black Holes

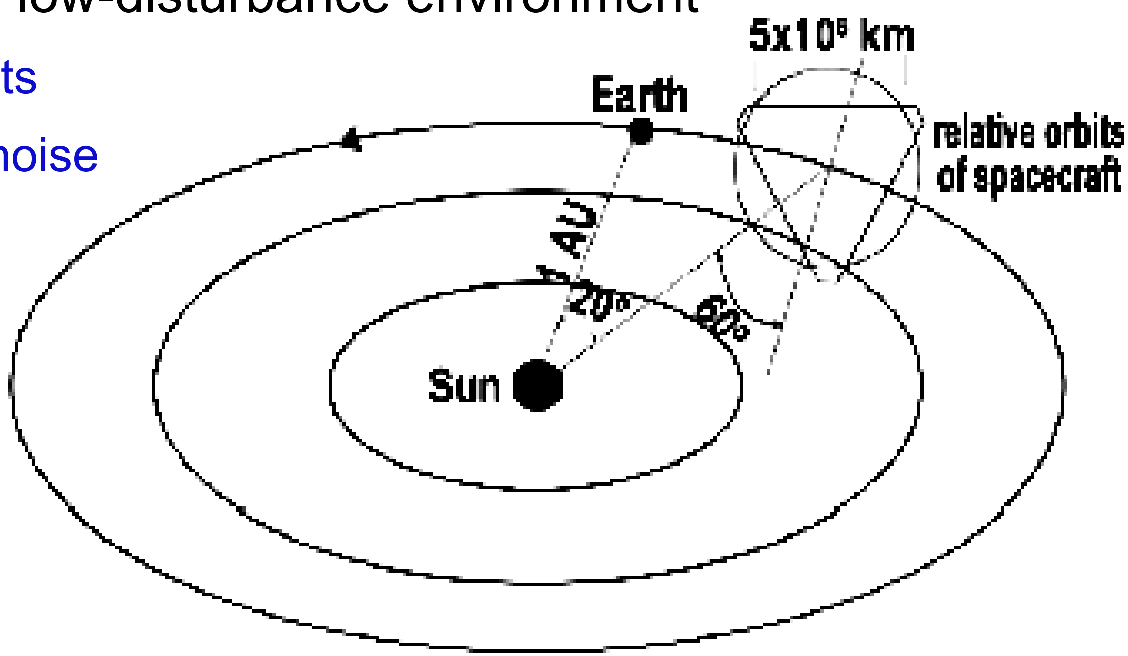
- Delta IV medium launches all 3 spacecraft
- Each Spacecraft coupled to propulsion module
  - Delta-V = 1.22 km/sec
  - Bi-propellant system with RCS for attitude control
  - Prop module is controlled by S/C computer
- 13-month cruise phase
- Prop. Modules jettisoned during setup phase



Orbits

Beyond Einstein: From the Big Bang to Black Holes

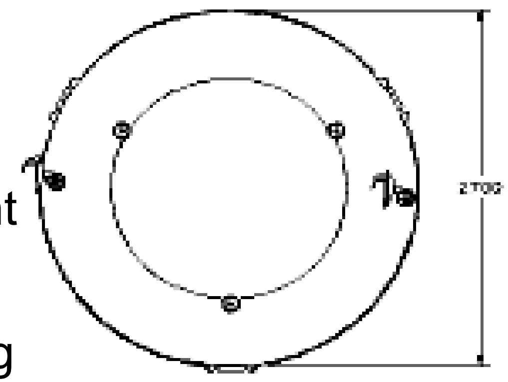
- Heliocentric orbit, trails Earth orbit by 20 degrees
- Constellation plane inclined 60 degrees with respect to the ecliptic
- Triangle rotates 1 degree per day (one complete revolution in one-year circuit)
- Constellation “breathes” ~ 1 degree per year
- Provides stable, low-disturbance environment
  - Thermal effects
  - Acceleration noise
  - Radiation



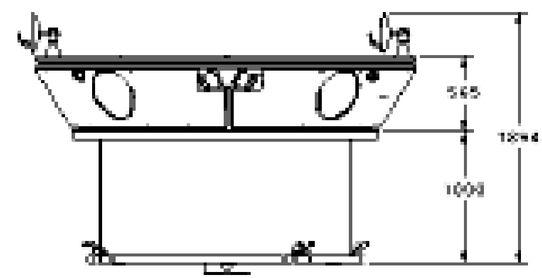
Spacecraft

Beyond Einstein: From the Big Bang to Black Holes

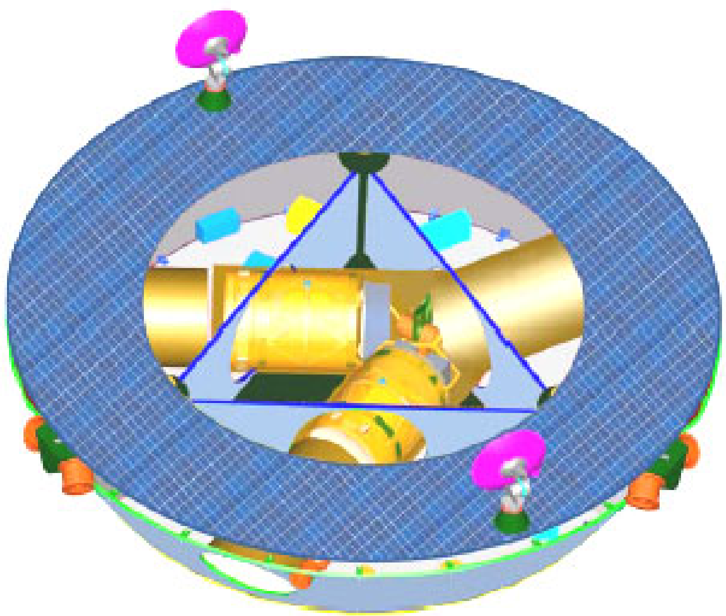
- 2.7 meter diameter X 0.57 meter high (not including prop. Module)
- Aluminum honeycomb and CFRP
- Triple-junction GaAs solar array, 3.45 square meters
- Straightforward subsystem designs with extensive flight heritage
- Electronics mount on top and bottom plates, depending on thermal considerations



TOP VIEW

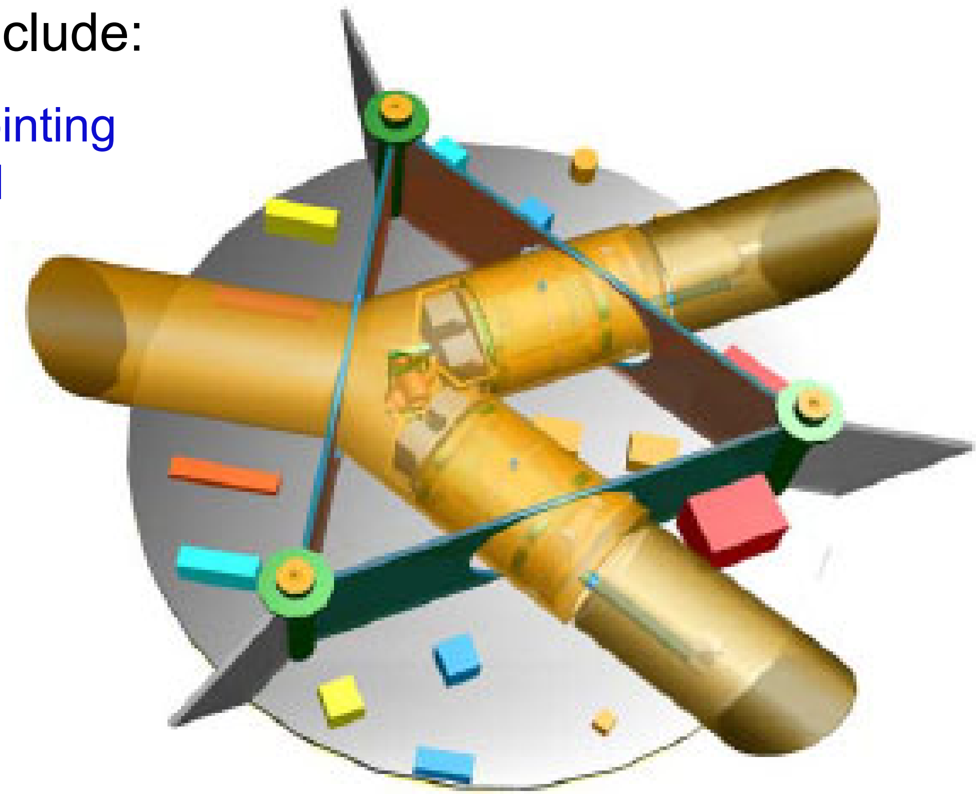


FRONT VIEW



Payload

- Two key functions:
  - Proof mass control and disturbance reduction (DRS)
  - Strain measurement (IMS)
- Supporting elements include:
  - Structure (Y-tube), pointing mechanisms, payload computer



Payload ~ DRS/GRS

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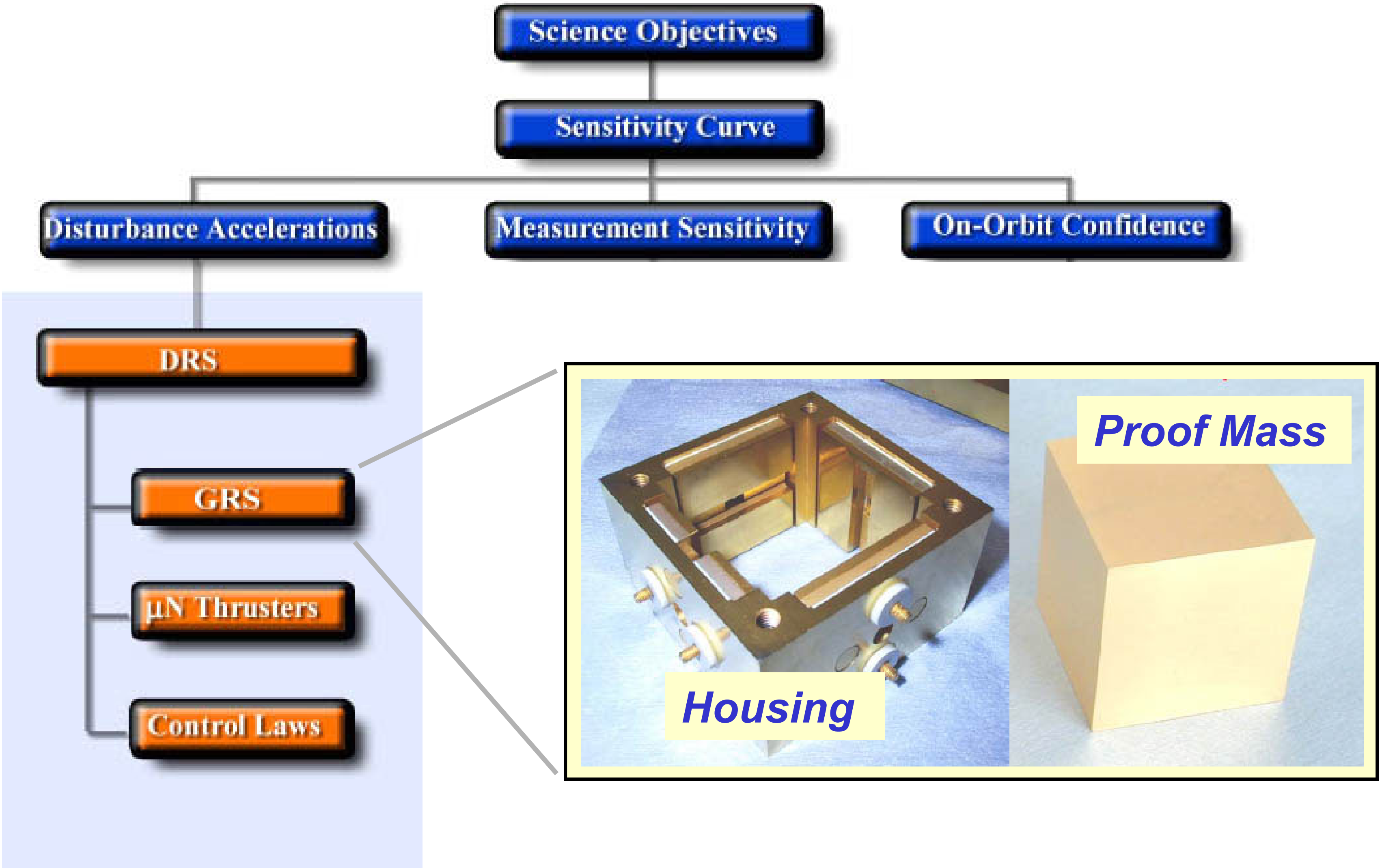
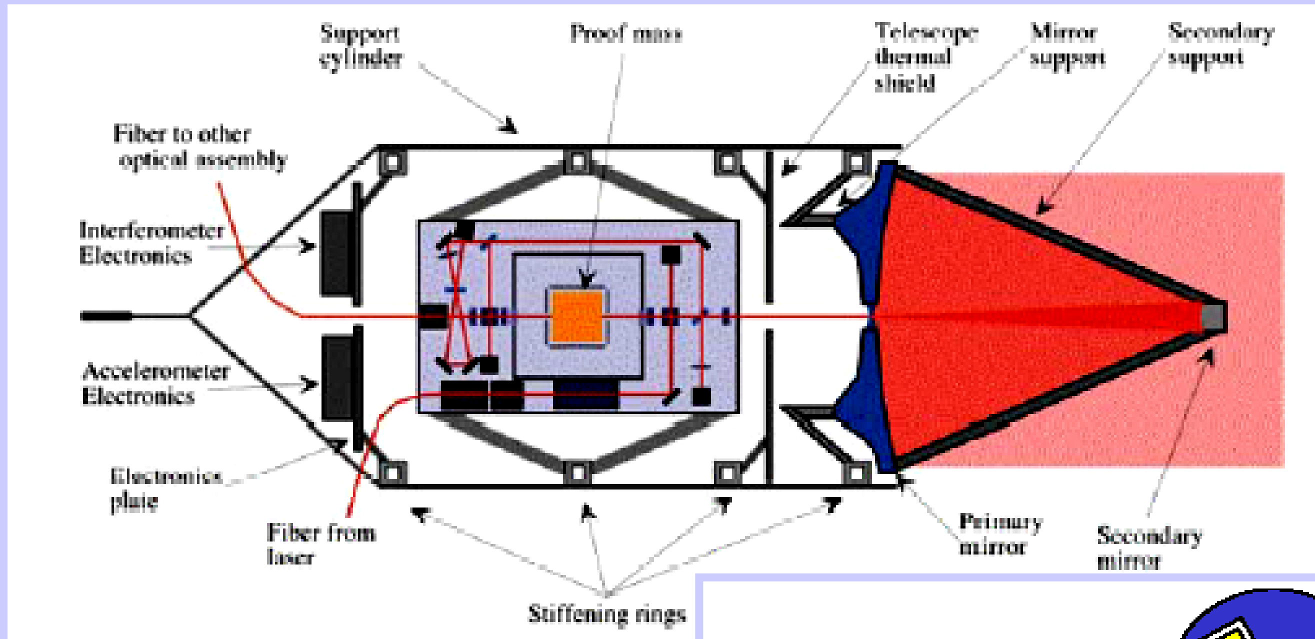
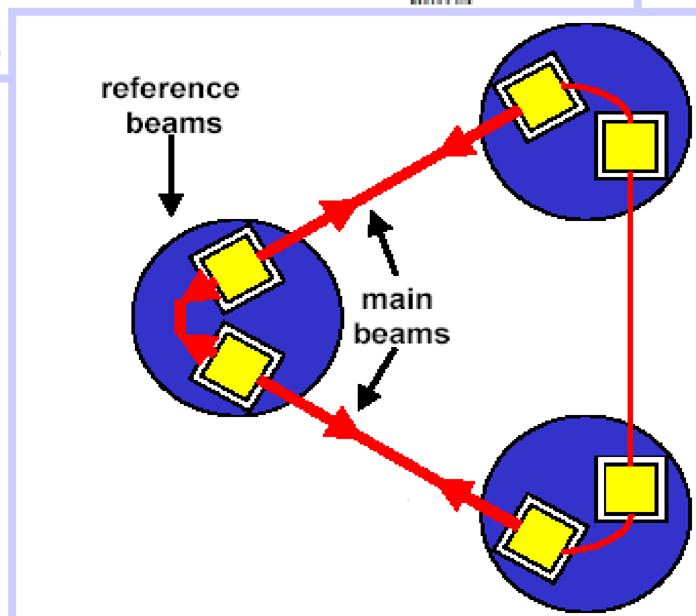


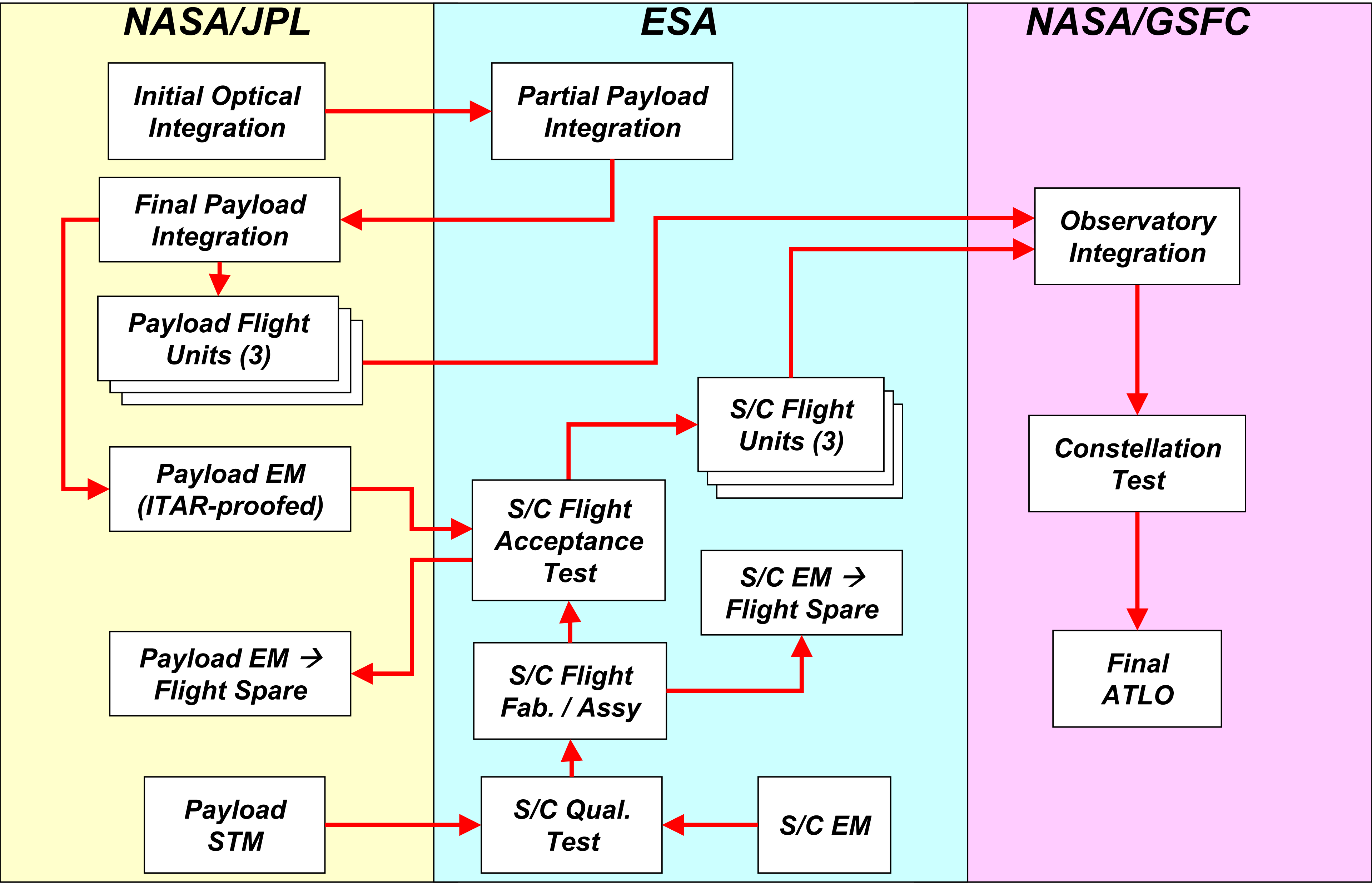
Payload ~ IMS

- Science Objectives
- Sensitivity Curve
- Measurement Sensitivity
- Interferometry Measurement System
  - Laser System
  - Phase Measurement
  - Ultra-Stable Structures
  - Frequency Noise Corrections





Strawman Integration Flow

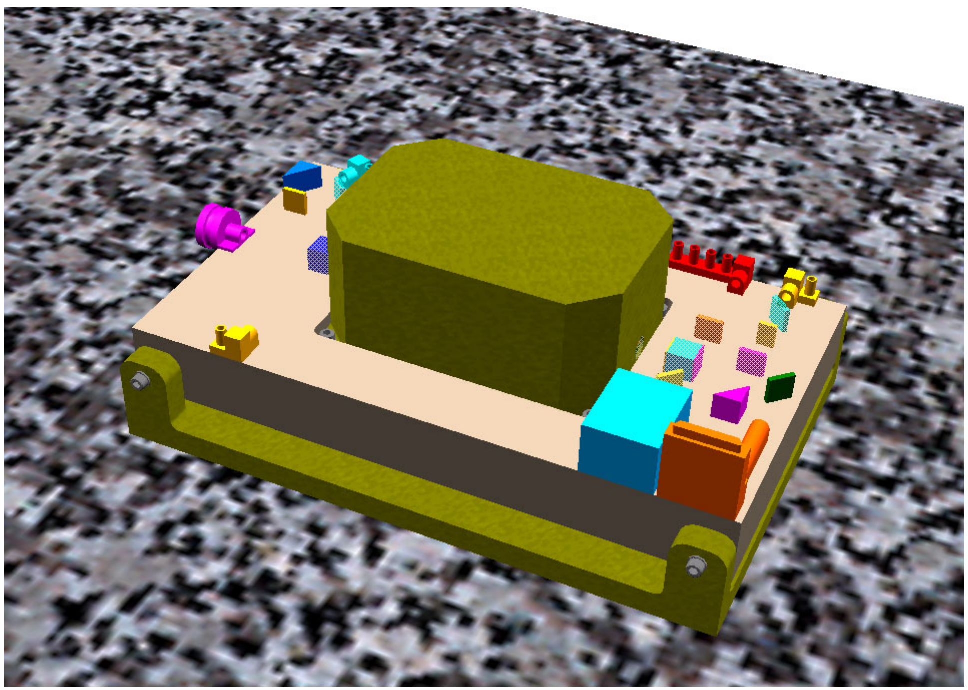


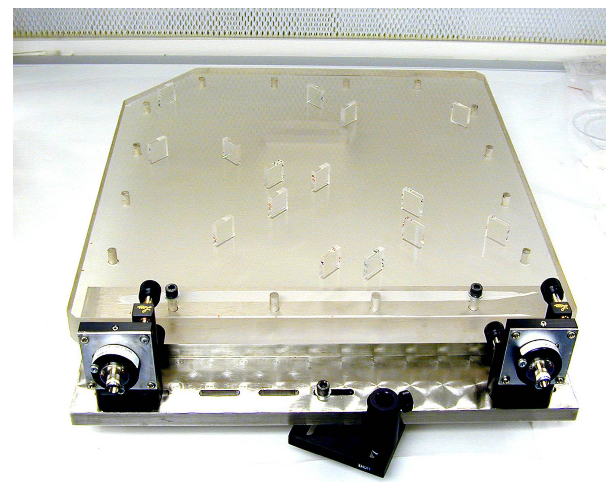
Verification During I&T

Step	Integration Components	Performance Tests	Environmental Test	Modeling
Initial IMS Integration	Dummy proof mass, ULE block, fiber, laser stabilization cavity, optics	Wavefront quality, contrast, scatter, bond stability	Vibration	None
Intermediate IMS Integration	Optical bench, laser, CCD, phase modulator, phase detector, ultra-stable oscillator, electronics	Detector noise, phase noise, laser frequency and amplitude noise, oscillator noise, pointing stability	TV, EMI/EMC	Frequency noise corrections, pointing, STOPG
Final IMS Integration	Electro-optical bench, telescope, star trackers	Wavefront quality, pointing actuation and stability, phase stability; IMS subsystem test	Vibration, Thermal, EMI/EMC, Magnetic	Frequency noise corrections, pointing, WFE at $5x10^6$ km, STOPG
GRS Integration	Initial optical assembly, charge management unit, flight proof mass, proof mass housing, caging and vacuum assembly	Charge control, proof mass actuation and control, vacuum level	Vibration, TV, EMI/EMC, Magnetic	GRS performance
Y-Tube Integration	Final optical assembly, Aft Fiber, Payload C&DH FSW, Y-Tube Structure	Pre-ship functional of GRS, Pre-ship functional of optical assembly, Pre-ship testing of thermal isolation, Pre-ship testing of phase readout, Pre-ship testing of laser stabilization	Mass properties, EMI/EMC, Magnetic, Acceptance-level vibration	STOPG, Frequency noise corrections
Observatory Integration	Spacecraft bus and payload	Displacement sensitivity, alignment sensitivity, pointing control, wavefront quality, frequency noise, gravity gradient	TV, EMI/EMC	STOPG, WFE at $5x10^6$ km, pointing
Constellation Testing	Three spacecraft	Michelson sensitivity, frequency noise rejection, lock acquisition, spacecraft communication, data processing, constellation testing	Thermal, Vibration, EMI/EMC, TV	DRS Performance, pointing, frequency noise corrections, science data simulator
Final Integration	Three spacecraft, Payload attach fitting, shipping container	Functional tests for launch campaign	None	None

Initial IMS Integration

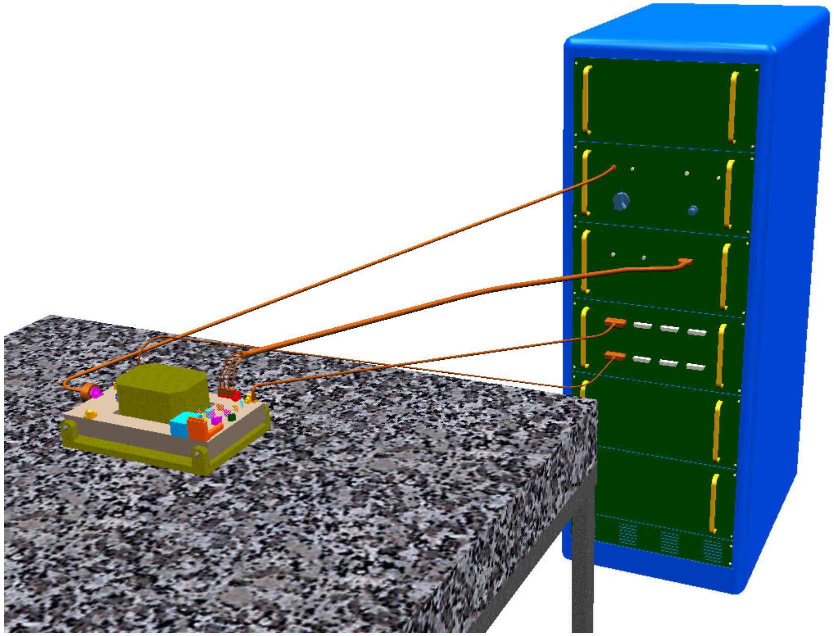
INTEGRATION COMPONENTS	PERFORMANCE TESTS	ENVIRONMENTAL TEST	MODELING
Dummy proof mass, ULE block, fiber, laser stabilization cavity, optics	Wavefront quality, contrast, scatter, bond stability	Vibration	None

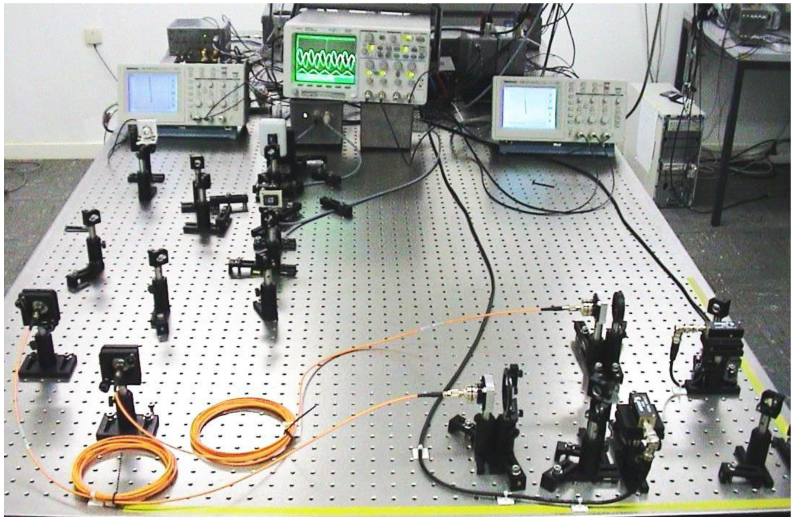




Intermediate IMS Integration

INTEGRATION COMPONENTS	PERFORMANCE TESTS	ENVIRONMENTAL TEST	MODELING
Optical bench, laser, CCD, phase modulator, phase detector, ultra-stable oscillator, electronics	Detector noise, phase noise, laser frequency and amplitude noise, oscillator noise, pointing stability	TV, EMI / EMC	Frequency noise corrections, pointing, STOPG

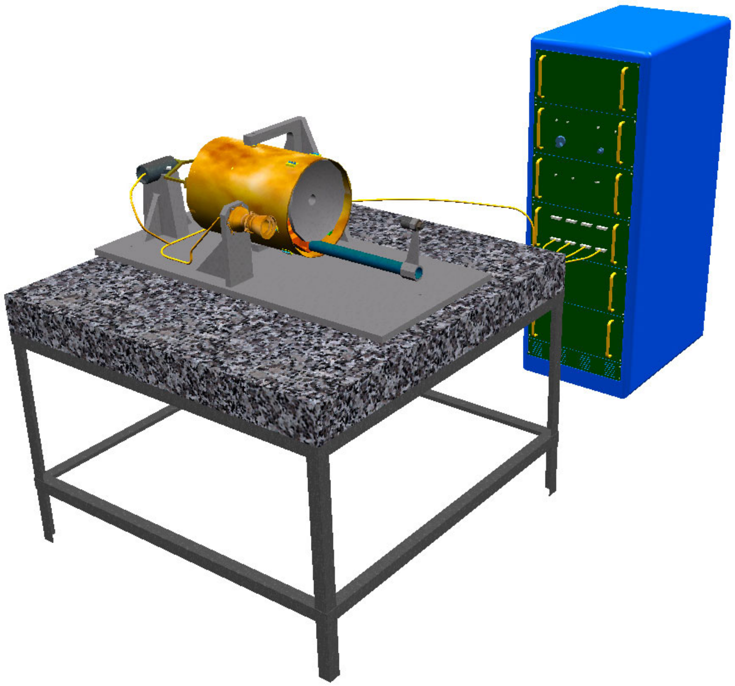


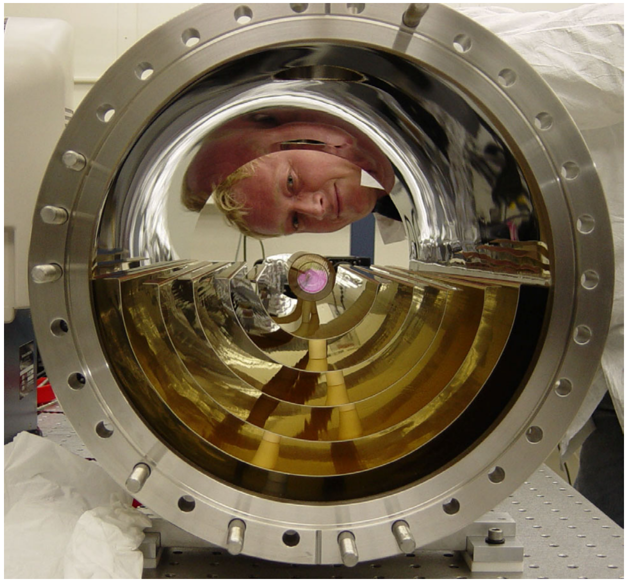


Final IMS Integration

Beyond Einstein: From the Big Bang to Black Holes

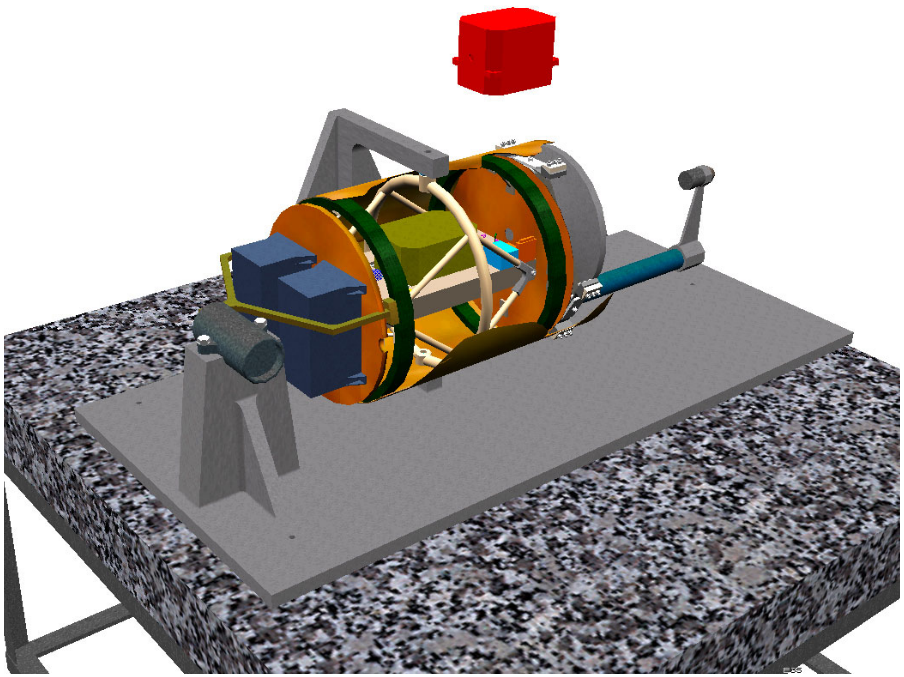
INTEGRATION COMPONENTS	PERFORMANCE TESTS	ENVIRONMENTAL TEST	MODELING
Electro-optical bench, telescope, star trackers	Wavefront quality, pointing actuation and stability, phase stability, IMS subsystem test	Vibration, Thermal, EMI / EMC, Magnetic	Frequency noise corrections, pointing, WFE at 5x 10^6 km, STOPG

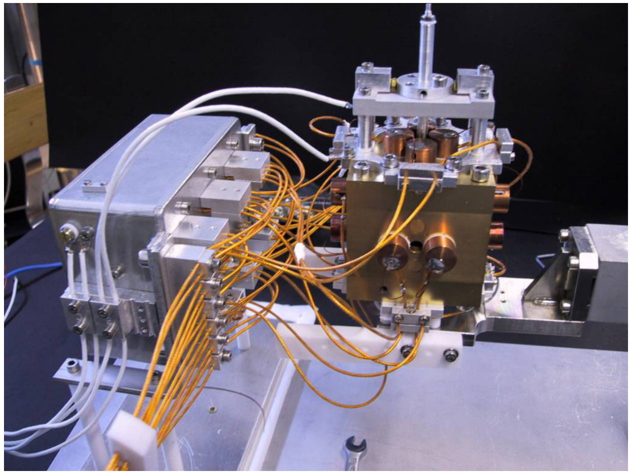




GRS Integration

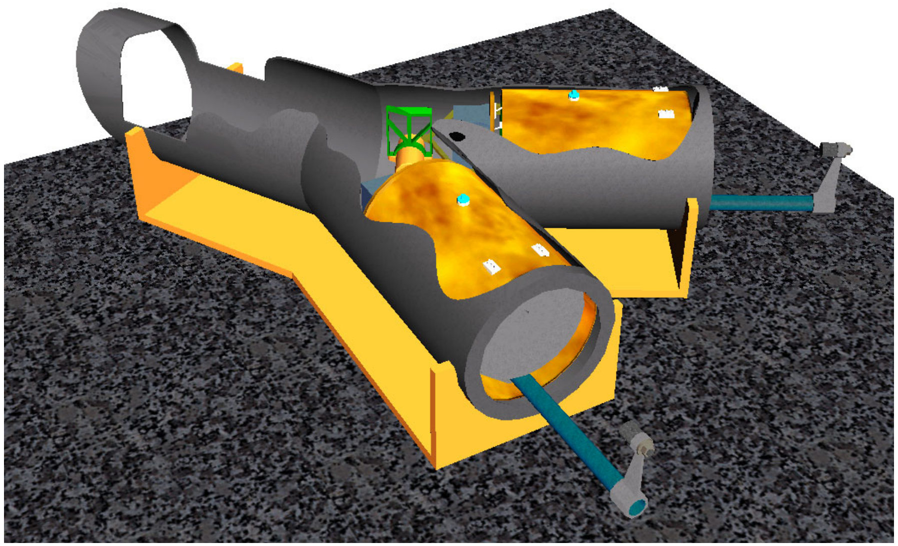
INTEGRATION COMPONENTS	PERFORMANCE TESTS	ENVIRONMENTAL TEST	MODELING
Initial optical assembly, charge management unit, flight proof mass, proof mass housing, caging and vacuum assembly	Charge control, proof mass actuation and control, vacuum level	Vibration, TV, EMI / EMC, Magnetic	GRS performance





Y-Tube Integration

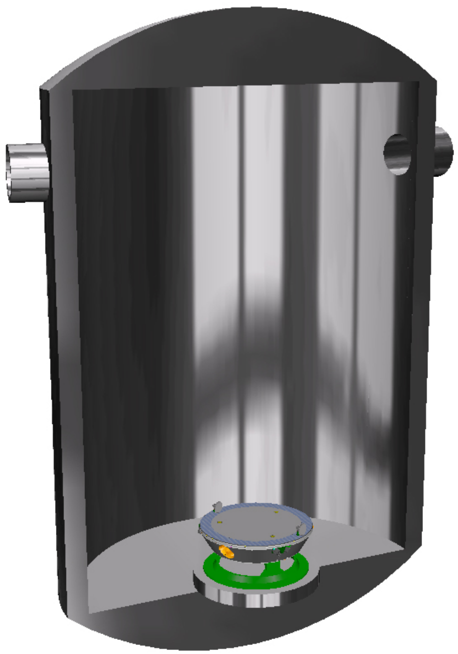
INTEGRATION COMPONENTS	PERFORMANCE TESTS	ENVIRONMENTAL TEST	MODELING
Final optical assembly, Aft Fiber, Payload C&DH FSW, Y-Tube Structure	Pre-ship functional of GRS, Pre-ship functional of optical assembly, Pre-ship testing of thermal isolation, Pre-ship testing of phase readout, Pre-ship testing of laser stabilization	Mass properties, EMI / EMC, Magnetic Acceptance level vibration	STOPG, Frequency noise corrections, Pointing



Observatory Integration

Beyond Einstein: From the Big Bang to Black Holes

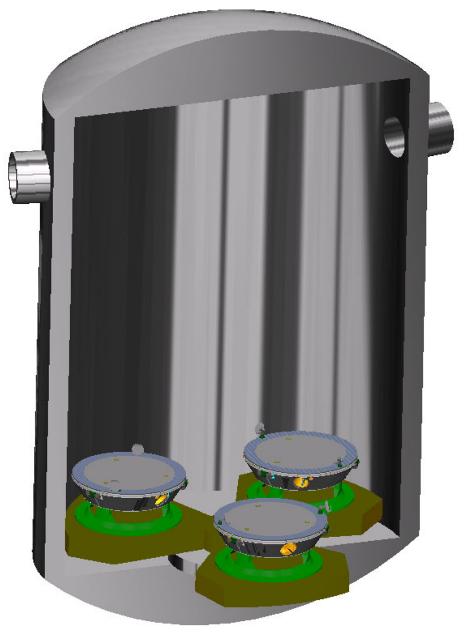
INTEGRATION COMPONENTS	PERFORMANCE TESTS	ENVIRONMENTAL TEST	MODELING
Spacecraft bus and payload	Displacement sensitivity, alignment sensitivity, pointing control, wavefront quality, frequency noise, gravity gradient	TV, EMI / EMC	STOPG, WFE at $5x10^6$ km

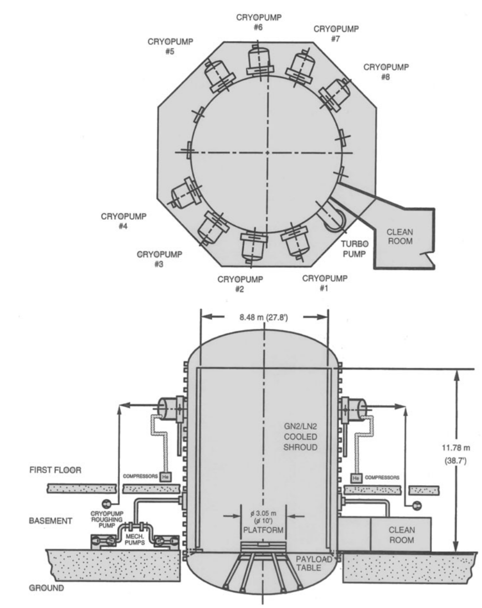


Constellation Testing

Beyond Einstein: From the Big Bang to Black Holes

INTEGRATION COMPONENTS	PERFORMANCE TESTS	ENVIRONMENTAL TEST	MODELING
Three spacecraft	Michelson sensitivity, frequency noise rejection, lock acquisition, spacecraft communication, data processing, constellation testing	Thermal, Vibration, EMI / EMC, TV	DRS Performance, pointing errors, frequency noise corrections, science data simulator

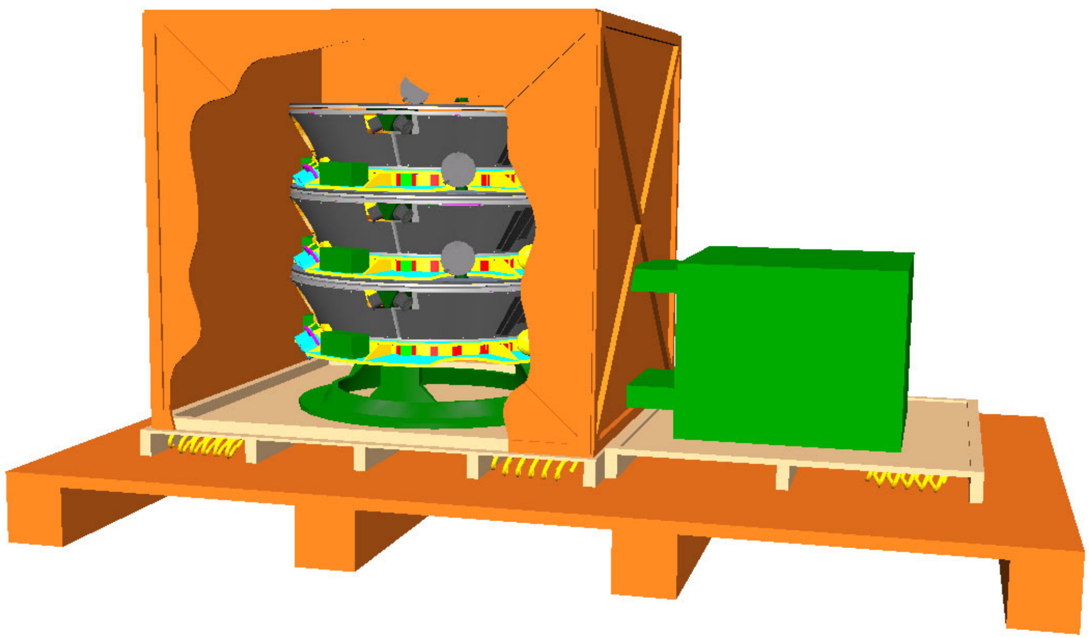




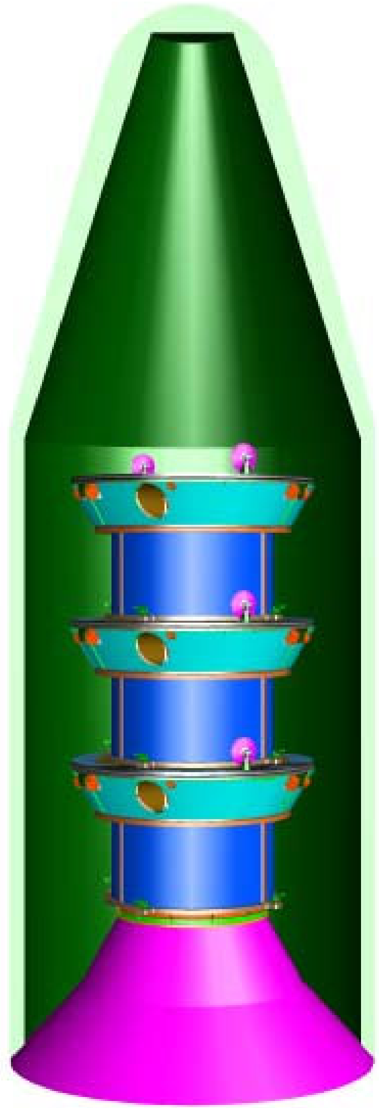
CHAMBER AND VACUUM SYSTEM SCHEMATIC
FACILITY 290

Final Integration

STEP	INTEGRATION COMPONENTS	PERFORMANCE TESTS	ENVIRONMENTAL TEST	MODELING
Final Integration	Three spacecraft, Payload attach fitting, shipping container	Functional tests for launch campaign	None	None



Launch



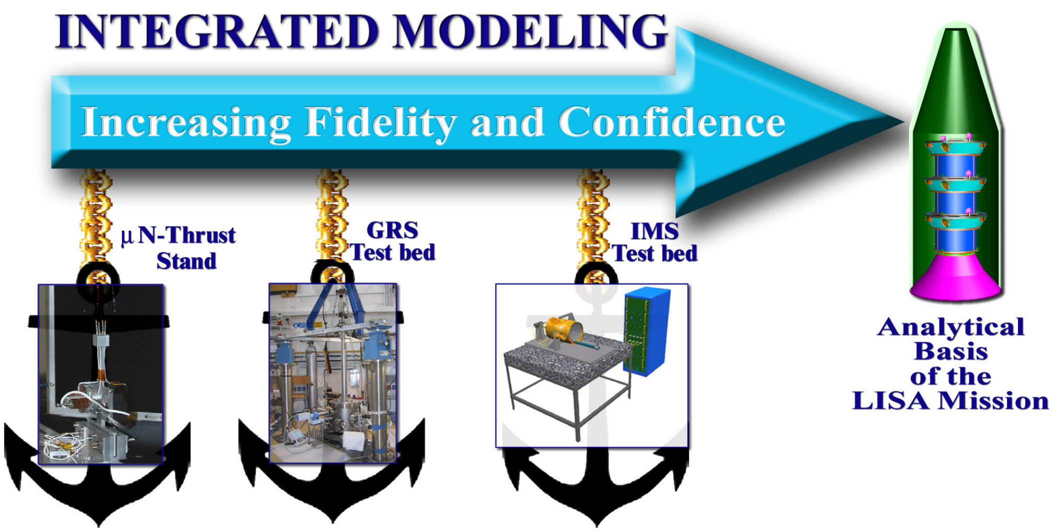
Operations Concept

- After set-up, operations are straightforward
  - 1 science mode
  - Periodic interruption for “tuneup”
    - IMS pointing
    - HGA pointing
- DSN 34 meter antenna, X-band, 7kbps down / 2 kbps up
- JPL Mission Operations Center
- One or more Science Data Analysis center(s)
- Performance monitoring to determine schedule for tuning

Integrated Modeling

Stephen Merkowitz

Integrated Modeling



- LISA has intricate interactions between subsystems that require an integrated approach to modeling and testing.
- Multidisciplinary modeling and analysis seamlessly interwoven into the systems engineering process.
- Models “anchored” by testbeds and flight demo.
- Distributed team - Contributions from NASA, ESA, Science Team, Industry, and Universities.
- Government lead effort. It is expected that SE&I contractor will heavily support.

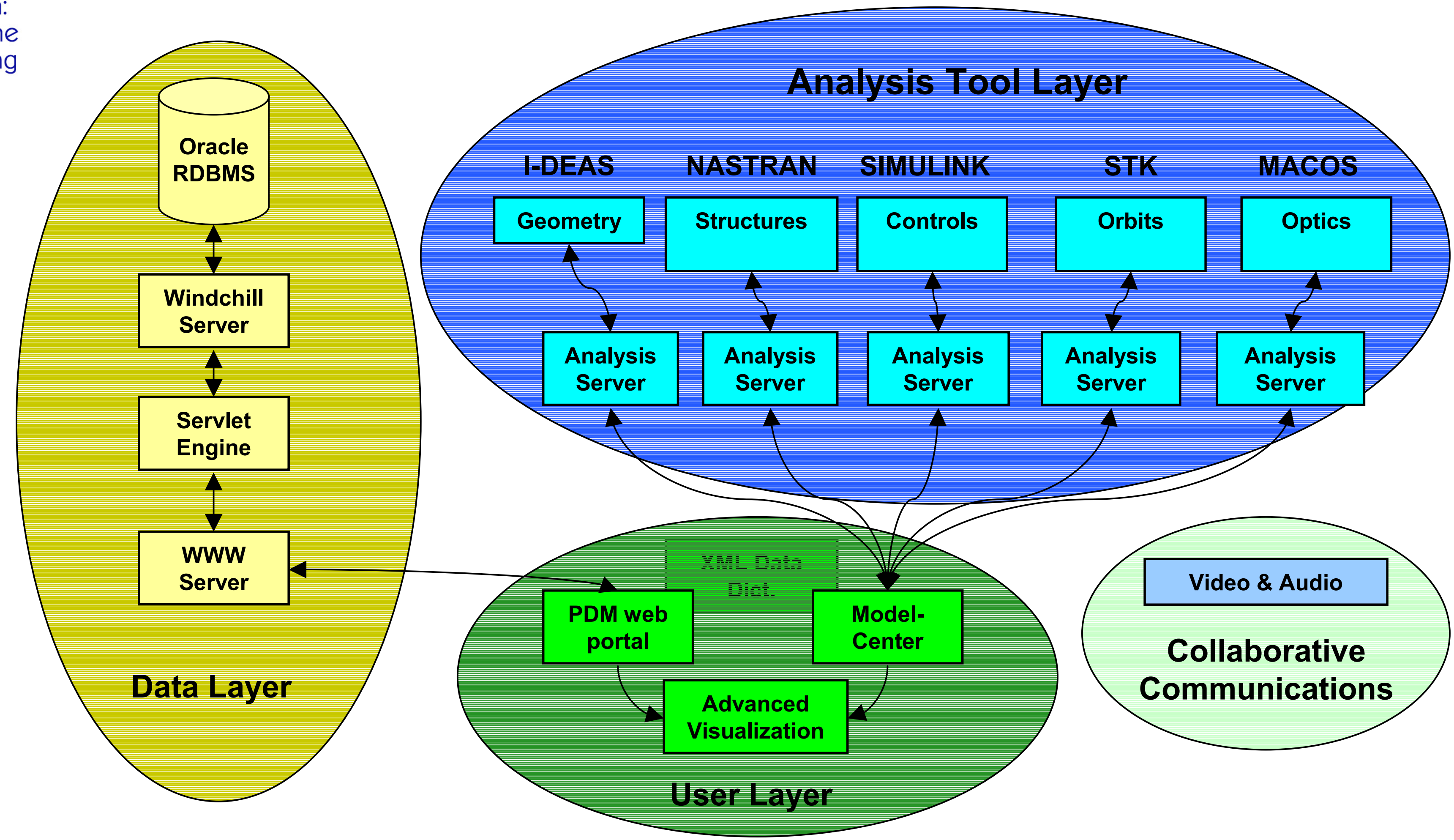
Plan for Developing Models

- Models initially developed by Project Integrated Modeling Team
- Final subsystem models are built and delivered by subsystem suppliers and SE&I contractor
- Core modeling team receives models, performs initial checks, and integrates into modeling environment
- Integrated Modeling Team works closely with both System Engineering and Technology Development

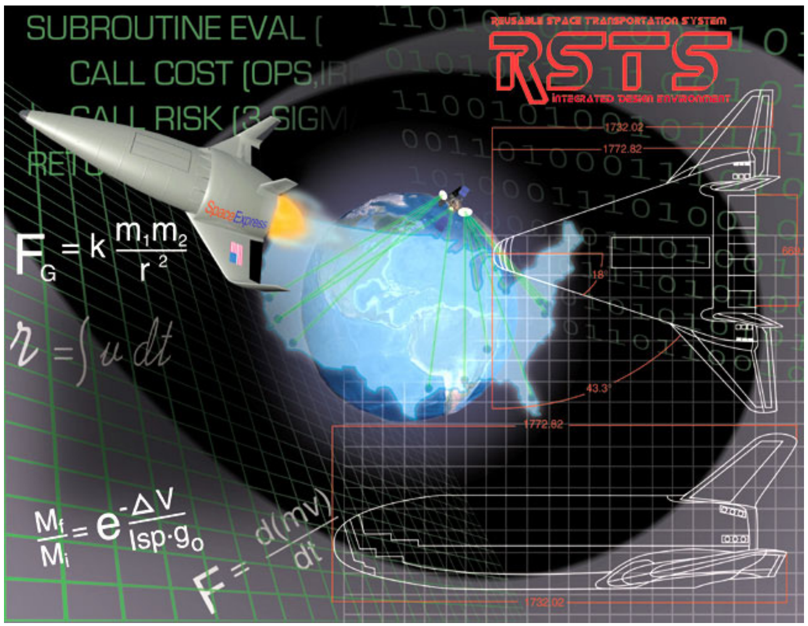
Integrated Modeling Phases

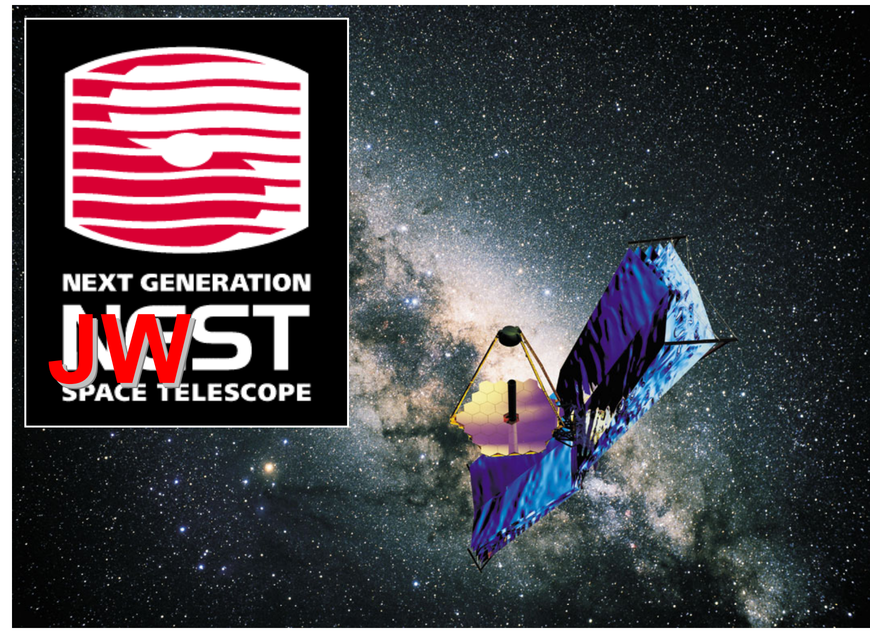
- Phase 1 (Formulation):
  - Establish baseline
  - Verify/derive system requirements
  - Risk assessment
  - Engineering trades
  - Modest integration
  - Feeds MCR
- Phase 2 (Formulation):
  - Engineering trades
  - Increased model integration
  - Feeds SRR
- Phase 3 (Formulation):
  - Full integration
  - Fully mature error trees and science data simulator
  - "Subtle" engineering trade studies
  - Publish Analytical Basis of the LISA Mission
  - Feeds PDR
- Phase 4 (Implementation):
  - Support I&T
  - Support science data simulator
  - Hardware in-the-loop tests
  - Support Flight Software
  - Support Operations
- Phase 5 (Post-Launch):
  - Support Operations
  - Support science data analysis

LISA Integrated Modeling Environment (LIME)



Partner & Leverage





Modeling Task Execution Flow

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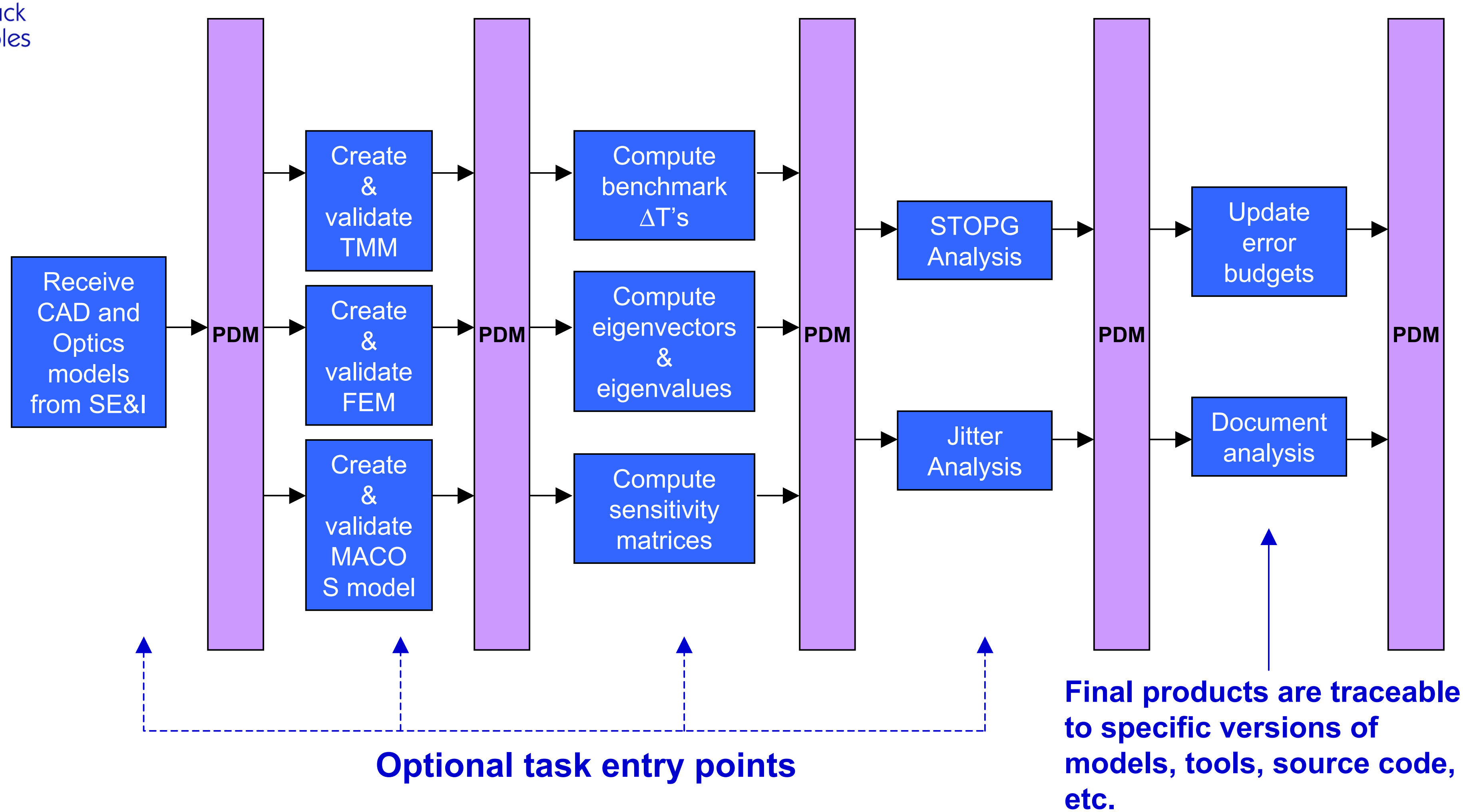
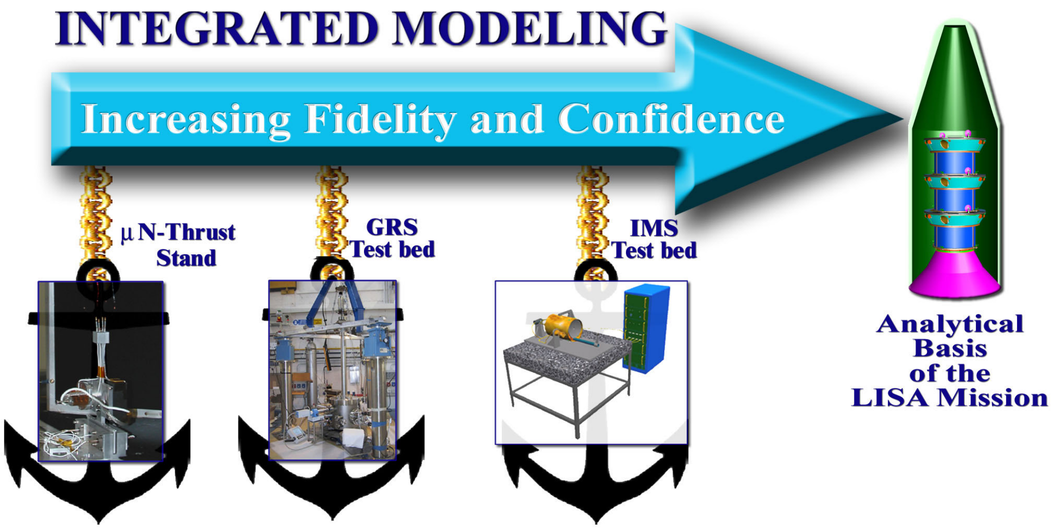
- Using LIME, a typical task might execute something like this…



Model Verification

- Modeling tools and techniques verified using benchmark problems
- Models built incrementally with verification procedures at each stage of development
- Verify the model synthesis (was the model assembled correctly)
  - Verification with simple benchmark tests for each discipline (e.g. FEM validity checks http://analyst.gsfc.nasa.gov/FEMCI/validitychecks/)
  - Benchmark tests for integrated modeling output
  - Comparison to existing model/results (e.g. contractor delivered data)
- Verify the model predictability:
  - Verification by similarity or re-use
  - Verification by cross-checking and review
  - Verification by test

Verification by Test



- Targeted studies
  - UW small force torsion pendulum
  - Kelvin Probe
  - Phase meter noise investigations
- Component level
  - µN-thrust stand
  - GRS test bed
  - Laser stabilization
- Subsystem level
  - IMS tester
  - DRS Simulator
  - SMART-2

End-To-End Modeling

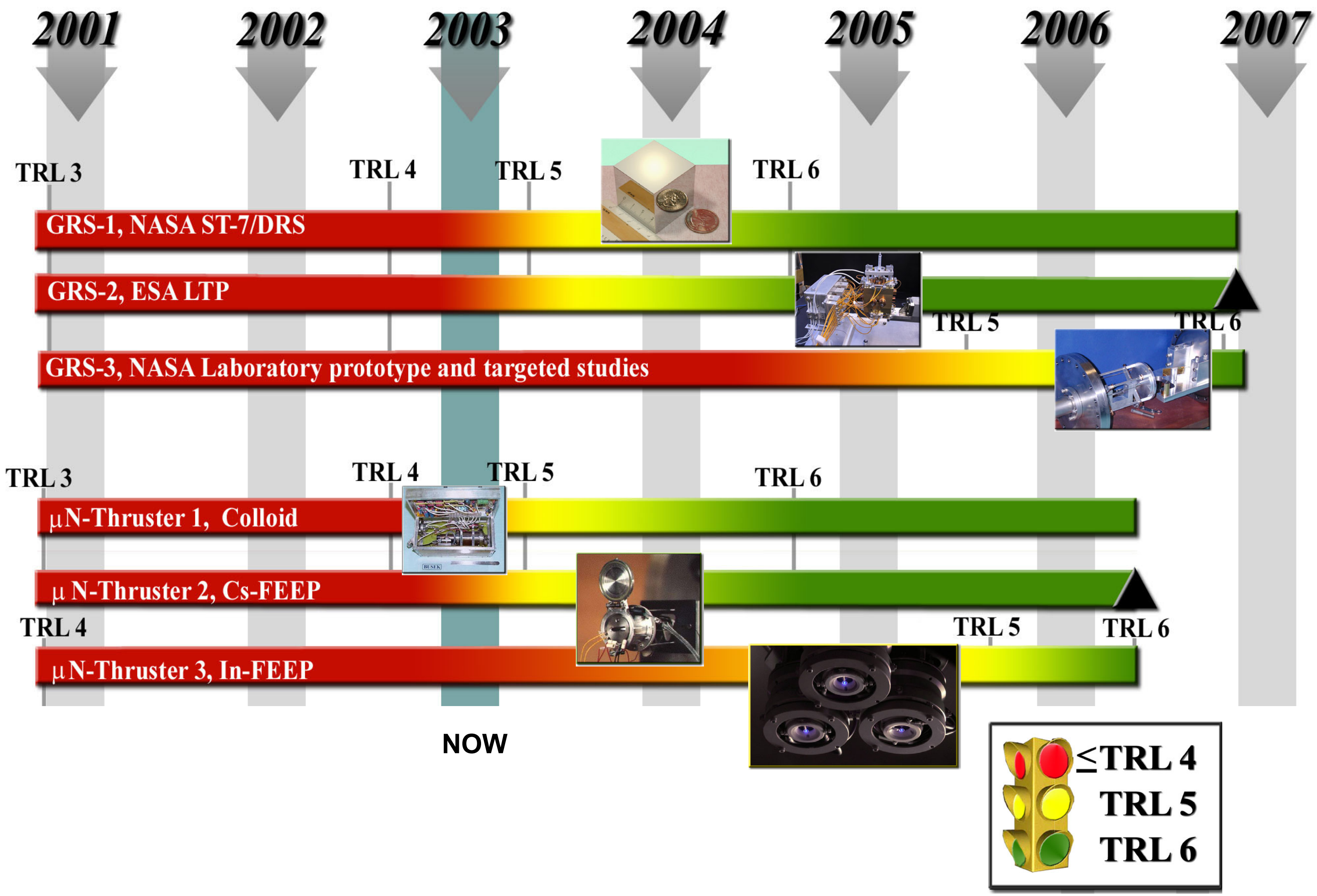
- Integrated System Model:
  - Completed system models:
    - Numerous (non-integrated) analyses and error budgets show sensitivity to all significant noise sources
    - 19 DOF (1 S/C & 2 PM) control simulation
    - First generation science data simulator
    - Time Delay Interferometry simulation
  - System models currently under development:
    - 57 DOF (3 S/C & 6 PM) control simulation
    - Several second generation science data simulators under development
    - Integrated error trees
    - STOPG analysis
- Completed Discipline Models for baseline design:
  - Solid Geometry Model
  - Thermal model
  - Finite element model
  - Self-gravity
  - Telescope Sensitivity Analysis
  - Quad-precision ray-trace of telescopes & 5 million km path
  - Orbit optimizations

Technical Challenges

Stephen Merkowitz

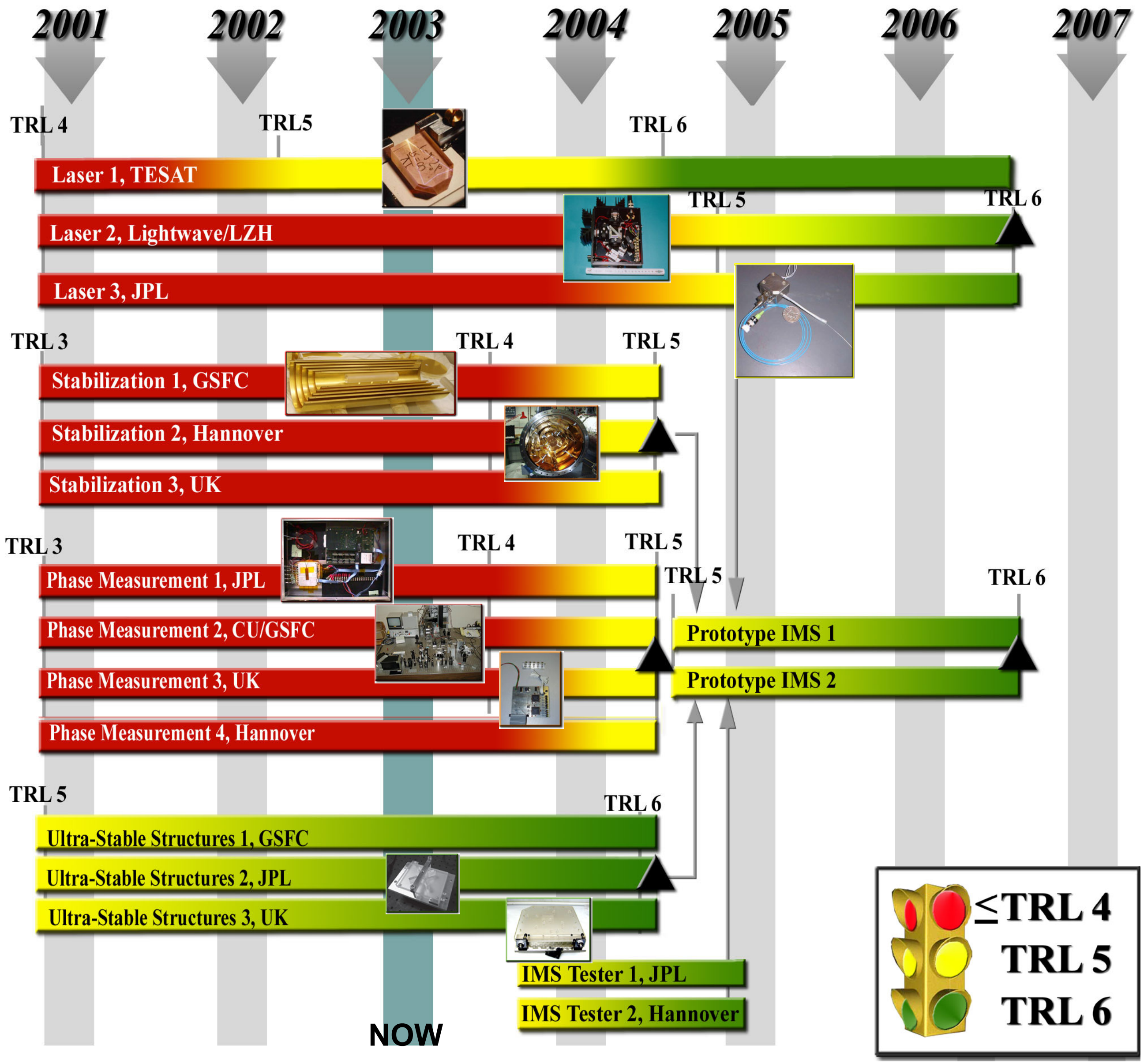
Technology Development Roadmap

Beyond Einstein: From the Big Bang to Black Holes



Technology Development Roadmap

Beyond Einstein: From the Big Bang to Black Holes



Design Challenges

- Integrated design
  - Clean interfaces
  - Modular testability
- Challenging requirements
  - Self-gravity
  - Structural stability
  - Thermal stability
  - Magnetic
- Integrated modeling
  - Model verification
  - Model precision
  - Multi-discipline integration
  - Configuration control

Verification and I&T Challenges

- Given the constraints:
  - GRS cannot be operated at full sensitivity on the ground
  - No 5 million km arms
  - No vibrationally and thermally quiet environment
- How do we:
  - Verify GRS performance
  - Demonstrate drag-free control
  - Verify frequency noise corrections
  - Verify thermal requirements
  - Verify self-gravity requirements
  - Verify structural stability requirements
  - Verify constellation acquisition
  - Verify constellation science mode

ITAR for LISA

Kevin N. Miller

NASA-ESA LISA LOA

KEY NASA RESPONSIBILITIES UNDER THE LOA

There is a signed LOA between ESA and NASA (June 2001), that is being updated to reflect changes in schedule and activities. The primary NASA responsibilities are:

- Designate a LISA study phase manager to work with an ESA-designated LISA study phase manager in the implementation of this Agreement
- Conduct, jointly with ESA, concept studies to define responsibilities for technology demonstration and subsequent LISA mission including collaborative mission design activities
- Conduct technology development for a joint ESA/NASA LISA Mission and a technology demonstration mission

NASA-ESA LISA LOA

KEY NASA RESPONSIBILITIES UNDER THE LOA (II)

- Define, jointly with ESA, system level interface requirements and specifications for the technology demonstration and LISA missions such as Interface requirements Documents (IRD), detailed Interface Control Documents (ICD), Assembly, Integration and Verification (AIV) requirements and provide ESA with technical information and documentation relative to the NASA Test Package needed by ESA to confirm engineering compatibility with the LISA technology demonstration mission SMART-2
- Define, jointly with ESA, measurable objectives for the LISA technology demonstration mission
- Select a NASA Co-Chair and ten NASA-sponsored scientists to participate in the LISA International Science Team [LIST], as well as additional NASA-sponsored scientists, as required, to serve on technical working groups under the direction of the LIST

NASA LISA Project ITAR Plan

Beyond Einstein: From the Big Bang to Black Holes

- A draft ITAR plan has been prepared by the Project
- This plan has been reviewed twice by Mr. John Hall, the NASA Export Administrator
- Mr. Hall and his technical advisors have also been briefed on the Project's I&T Flow Plan as well as the strategy for using the ITTs, and have no issue with this approach
- Each step has been carefully reviewed with Agency ITAR experts before moving forward:
  - Discussed and showed models to Mr. Hall before sending to ESA
  - Discussed LISA web site and what could be posted/not posted with Mr. Hall
- The Project will continue to work closely with the Agency and Center Export Control offices

PRIMARY ELEMENTS OF THE LISA ITAR PLAN

- Summary
- General Overview
  - International Traffic in Arms Regulations
  - Letter of Agreement
  - Memorandum of Understanding
- Stages
  - Formulation
  - Implementation
- LISA Industry Prime/Technical Assistance Agreements/Non-Disclosure Agreements
  - Technical Assistance Agreements
  - Non-Disclosure Agreements

PRIMARY ELEMENTS OF THE LISA ITAR PLAN (II)

- Technology Transfer
  - Technical Data
  - NASA Provided Software
  - Destination Control Statement
  - Public Release of NASA Technical Data/Software
- LISA Customs/Transportation Issues (Hardware)
  - Temporary Exports of NASA Hardware
  - Permanent Exports of NASA Hardware
  - Return of NASA Hardware from Foreign Partner Facilities
  - NASA Importation of ESA Hardware

PRIMARY ELEMENTS OF THE LISA ITAR PLAN (III)

- NASA Importation of LISA Items Procured Outside of the United States
- Hand-carry of NASA Hardware from the United States

- Foreign Visitor Processing
  - Short Term
  - Long Term
- Facilities
  - Office Space
  - Computer Access
- Configuration Management/Documentation Management
  - Developing Processes to Control Access to ITAR Sensitive Documentation

PRIMARY ELEMENTS OF THE LISA ITAR PLAN (IV)

- Project Reviews/System Engineering Meetings
  - "Need to Know" arguments must be satisfied
  - Need to partition meetings and set agendas accordingly
- Interface with Vendors
  - Prime Contractors
    - Sub-Contractors
  - Principal Investigators
    - Universities

Governing Documents/Directives

Beyond Einstein: From the Big Bang to Black Holes

Documents:

- The Export Administration Regulations (EAR) – 15 C.F.R. 730-774, Department of Commerce
- The International Traffic in Arms Regulations (ITAR) – 22 C.F.R. 120-130, Department of State

Directives:

- NPD 2190.1, NASA Export Control Program
- NPG 2190, Procedures and Guidelines for the NASA Export Control Program (Draft)
- NPD 2210.1, External Release of NASA Software
- NPG 2210.1, External Release of NASA Software
- NPG 2800.1, Managing Information Technology

Procurement

Jerry P. Edmond

Procurement

- Rules of Engagement
  - RFI Period
    - During task dissemination and delivery
    - Before release of Draft Study RFP
    - After release of Final Study RFP
- Purpose of RFI Period
  - Allow the Government to determine the best course of action
    - Scope
    - Acquisition Strategy
- Planned Acquisition Strategy
  - Strategy has NOT been approved By NASA GSFC/HQ's Management
  - Phased Acquisition is planned
    - Issue RFP for Study Contract with award to two vendors for a Fixed Priced
    - Issue RFP for Implementation with award to one vendor for LISA SE&I (Cost Plus with Award and Incentive Fees)

Procurement

- Encourage Small Business Participation
  - RFI Phase Potential Bidder's List Released to Small Business Representative
  - Small Business Representative Contact and Information
    - LISA GSFC Small Business Representative Simone Rollings (301) 286-4679

Initial Study Task

Mark Herring / Jordan Camp

Topics

- Purpose of Initial Study Task
- Schedule and Format
- Task Description

Purpose of Task

- Tool to allow project staff to learn more about industry capabilities
- Supports generation of RFP
- Supports bidder efforts to learn more about LISA

Schedule and Format

- Response requested in Slide Show format
  - Submit PowerPoint or PDF file
- Charts due June 30, COB
  - E-mail to list provided
- Individual Bidder Presentations at GSFC July 1 and 2
  - Two hours for presentation
  - Q&A period
- Follow-up written report due July 15
  - Approximately 25 pages

Implementation Assumptions

- The study task is based on the LISA architecture and implementation planning described in the TRIP Report and in this briefing.
  - In case of conflict, this briefing prevails
- The assumptions can and will change before the RFP is issued---and throughout the formulation phase

Task Description

- One function of the System Engineering Office (SEO) is to ensure the technical integrity of the LISA mission. How do you plan to support the SEO in overall SE Management including coordination & communication, documentation, I&T planning and execution?
- ITAR Considerations: Given the integrated nature of LISA (both technical and teaming arrangements) and the structure of the Systems Engineering Office (IST&ITT), what is your approach to handling ITAR efficiently? How will information be exchanged between the relevant partners in a timely fashion?
- Describe a possible approach for integrated constellation testing that includes the setup and laser link acquisition strategy and normal science mode operations.
- Address the specific technical questions in the following charts

Technical Tasks

- LISA I&T program will involve a large number of detailed technical tasks to ensure proper assembly of spacecraft
  - interferometry, thermal, vacuum, etc....
- We would like to get some feeling for the technical capabilities of the contractors
- Thus we ask the contractors to provide *conceptual descriptions* of how they would go about verifying a number of mission requirements
  - estimate of cost, time, equipment, and manpower

Proof Mass Enclosure Vacuum

- After bakeout, the proof mass enclosure vacuum level must meet the following requirements
  - total pressure < 10^{-7} torr
  - hydrocarbon partial pressure (AMU > 44) < 10^{-10} torr
  - gas ‘bursts’ of pressure > 10^{-7} torr over 1000 sec, at rate < 1 / day
- Assumptions
  - enclosure has a volume of 0.03 liter
  - enclosure pumped by a 10 liter / sec ion pump
  - access to the enclosure provided by a connection with 10 liter / sec conductance

Output Beam Wavefront

- After magnification by the expanding telescope, the output beam wavefront distortion must meet the following requirement
  - Peak-peak deviation from a planar wavefront < λ / 50
- Assumptions
  - beam has 30 cm diameter after exiting spacecraft
  - ignore obscuration at center of beam from Cassegrain design

Laser Noise

- The noise on the laser light must meet the following requirements at 1 mHz
  - intensity noise $\Delta I / I < 10^{-5}$ / sqrt (Hz)
  - frequency noise $\Delta f / f < 30$ Hz / sqrt (Hz)
  - pointing noise 1 m from proof mass < 1 micron / sqrt (Hz)
- Assumptions:
  - output beam diameter of 1 mm (telescope not yet installed)
  - laser is frequency stabilized and exits spacecraft after being reflected off of fixed proof mass.

Temperature Variation at Proof Mass

- The temperature variation at the proof mass, on orbit, must be < 10-6 K / sqrt(Hz) at 1 mHz
- Assumptions:
  1. spacecraft temperature variation on orbit = 10-3 K / sqrt (Hz)
  2. I&T room temperature variation = 10-1 K / sqrt (Hz)
  3. test is done with SC fully assembled